RSVP

The AGS Conceptual Design Report
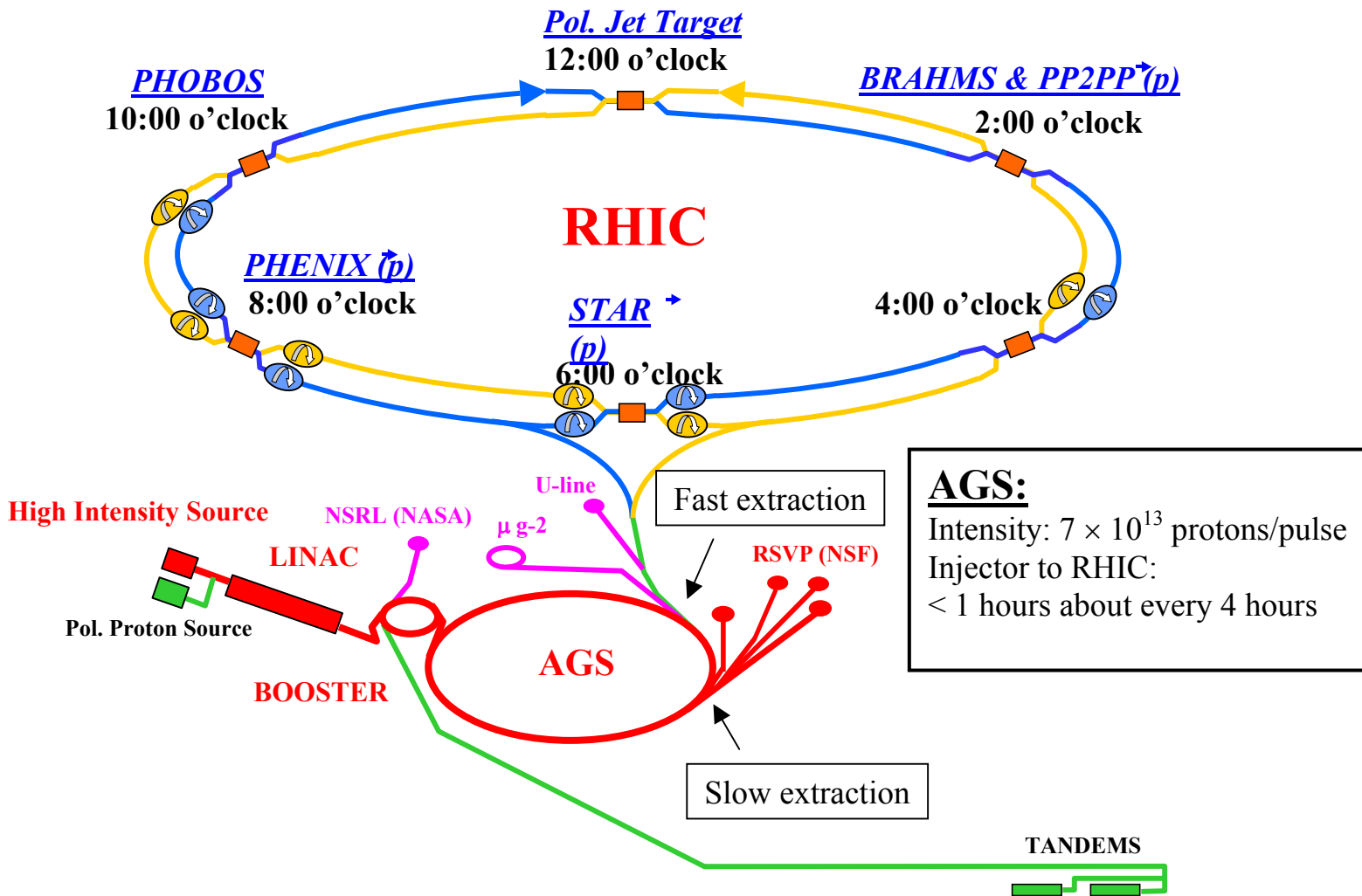
Pol. Jet Target
12:00 o'clock

PHOBOS
10:00 o'clock

BRAHMS & PP2PP (p)
2:00 o'clock

RHIC

PHENIX (p)
8:00 o'clock

STAR (p)
6:00 o'clock

4:00 o'clock

U-line

Fast extraction

AGS:
Intensity: 7×10^{13} protons/pulse
Injector to RHIC:
< 1 hours about every 4 hours

High Intensity Source

NSRL (NASA)

μ g-2

LINAC

RSVP (NSF)

Pol. Proton Source

AGS

BOOSTER

Slow extraction

TANDEMS

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Chapter I, The Overall Picture and RSVP Management

1. Introduction

The Rare Symmetry violating Processes (RSVP) Project and Program at Brookhaven National Laboratory (BNL) is a Major Research Equipment - Facility Construction (MRE-FC) project and research program of the National Science Foundation (NSF). It was developed as a means to carry out a set of very compelling particle physics experiments at BNL's Alternating Gradient Synchrotron (AGS) machine after the U.S. Department of Energy (DOE) terminated the use of this machine as a DOE user facility in U.S. Fiscal Year (FY) 1999. RSVP at this time, consists of two separate experiments, KOPIO and MECO that will be constructed over the next several years and then operated to produce physics results.

The RSVP project will be incorporated into the C-AD complex of accelerators and beam lines. In this chapter we present the modifications and new construction that are required to provide the high intensity beams for RSVP and the impact on the facility as a whole.

The Collider-Accelerator Department (C-AD) complex, figure 1, constitutes a number of accelerators including two Tandem Van de Graff accelerators, a 200 MeV linear accelerator LINAC, a Booster synchrotron, the Alternating Gradient Synchrotron and the Relativistic Heavy Ions Collider. These are combined to serve several programmatic operations to deliver a variety of beams to the user community. These include:

- The Tandem/ Booster/AGS as injectors to the Relativistic Heavy Ions Collider (RHIC)
- The LINAC/Booster/AGS as injectors of polarized protons to RHIC.
- The Tandem/Booster delivery of ion beams to the NASA Space Radiation Laboratory (NSRL).
- The Tandem/Booster/AGS delivery of ions to the NASA-AGS beam line.
- The LINAC delivery of high intensity protons to the Brookhaven Linear Isotope Production facility (BLIP).
- The LINAC/Booster/AGS delivery of high intensity proton beams to the RSVP experiments, the focus of this document.

In order to maintain high efficiency significant versatility is required. This includes the capability of operating multiple programs simultaneously achieved via pulse to pulse modulated time sharing (PPM) as well as the ability to make fast changes of state requiring few minutes and is done entirely via computer controls (mode switching). A given program that can be performed in a time sharing mode (either via PPM or a mode switching) would be defined as capable of concurrent mode operation. The Booster delivery of ions to the NSRL and the AGS, or polarized protons or high intensity protons to the AGS may be accomplished in concurrent mode operation. The same is true of the AGS delivering ions or polarized protons to RHIC and high intensity protons to RSVP. On the other hand, the AGS Switchyard must be capable of delivering high intensity protons to RSVP experiments and ions to a high energy NASA beam line. The operation of RSVP and the NASA-AGS program cannot run concurrently as high intensity protons must not activate the NASA beam components due to the required frequent

experimenter access into the beam line. Similarly the delivery of beams to the two RSVP experiments are not concurrent.
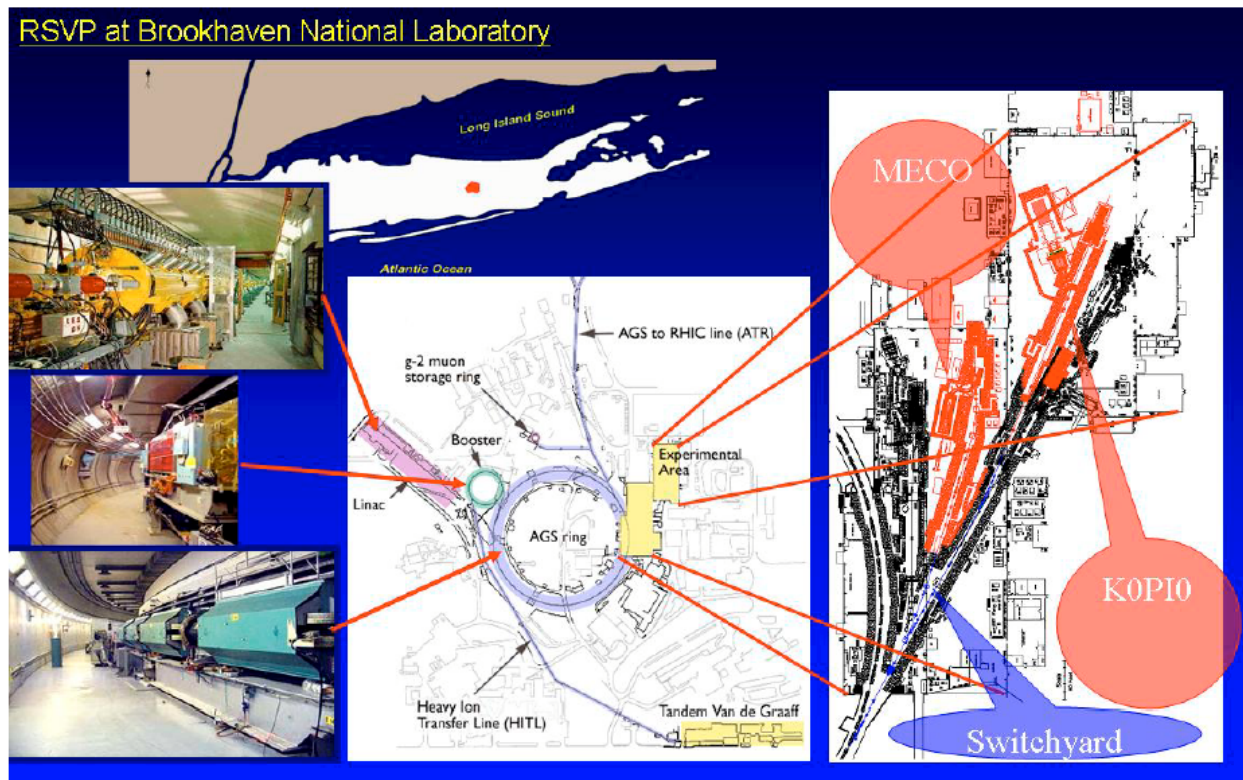
Figure 1: The Linac Booster and AGS and overall accelerator complex and the layout of the KOPIO and MECO Experimental Areas at the Collider-Accelerator Department Facilities.

The C-AD follows strict guidelines and a rigorous review process for all installed systems. This includes conventional safety requirements and to comply with the goal to keep radiation exposure to C-AD workers and equipment as low as reasonably achievable (ALARA) and enforces limits on beam losses and radiation levels for environmental protection. The C-AD safety systems include access controls to radiation areas, active radiation monitoring to ensure radiation levels follow predetermined guidelines, and ground water activation monitoring.

2. AGS RSVP Project Management

2.1 Management Basis

The RSVP Project will be managed for the NSF through the RSVP Project Office and will be overseen by the Joint Oversight Group (JOG) of the two agencies as provided for in the NSF-DOE MOU. This AGS Management Plan will capture the elements of the management of the BNL/AGS-RSVP project and become part of the RSVP Management Plan for the RSVP Project. The DOE Site Office at BNL, through the Federal Project Director, will oversee the Laboratory related aspects of the RSVP Project (permanent modifications of the AGS, its extraction system and proton beam lines, and experiment installations). In addition, the Laboratory Associate

Director for High Energy and Nuclear Physics will provide additional direct oversight to the BNL/AGS-RSVP project.

Specific details about the management structure and governing policy are provided in the NSF-DOE MOU, provided as an Appendix to the RSVP Management Plan.

2.2 RSVP Project Organization

The RSVP Project organization chart is shown in figure 2 below. In addition to reporting directly to the RSVP Project office as shown in the chart, the BNL/AGS-RSVP project also reports directly to the BNL Associate Director for High Energy and Nuclear Physics, The DOE Brookhaven Area Office and the head of the Collider Accelerator Department. The approach is to satisfy the needs of the RSVP Project office consistent with guidance provided to the BNL/AGS-RSVP project by individuals in the other reporting lines. Conflicts that cannot be resolved will need to be resolved at the NSF/DOE level.
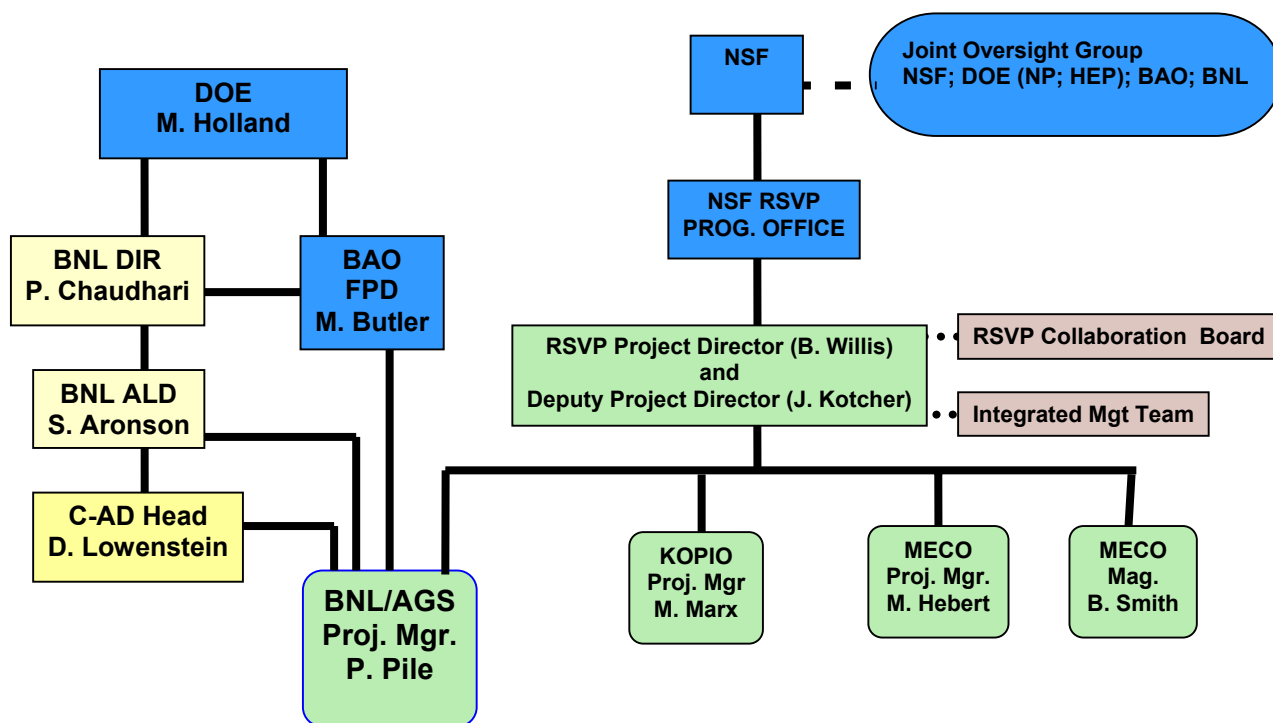
Figure 2. RSVP Project Organization chart

The BNL/AGS-RSVP project organization chart is shown in figure 3 below with, except for the RSVP Project office, all upper level reporting lines removed. The level 3 project managers listed in the boxes reporting to the AGS project are members of the C-AD and have separate management lines to answer to and do not have full-time responsibility to RSVP. The level 3 subsystem managers are responsible to insure work gets scheduled to meet established

milestones. The C-AD Chair has the responsibility to insure there is adequate staff to meet the milestones. The deputy AGS Upgrades Project manager has the responsibility to report such needs. The C-AD chief mechanical and electrical engineers are responsible for insuring the necessary engineering resources are made available.
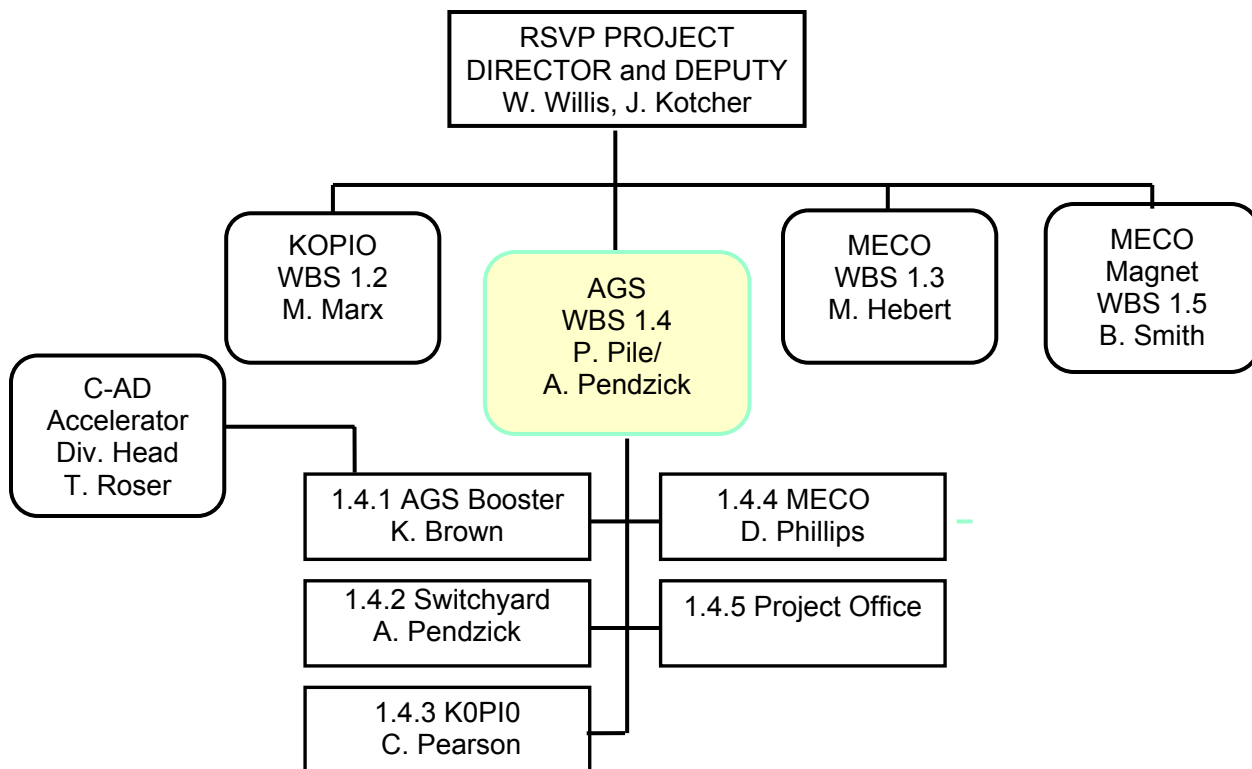
Figure 3. BNL/AGS-RSVP project organizational chart.

2.3 Management during construction phase

Work will be defined by yearly MOU's between the BNL/AGS-RSVP project, RSVP Project office and experiments. Work will be performed using C-AD personnel together with new hires to either back-fill for RHIC needs or do work for RSVP. In all instances RHIC priority will be maintained. Conflicts will be handled with the goal to not seriously impact established RSVP milestones. At times this may require overtime or second shift work.

RSVP representatives will be required to participate in the ES&F Division usual "Monday" ES&F Division Staff Meeting where the week's Division work plan is discussed. Plan to continue weekly RSVP specific meetings (these began in July 2004), including relevant Department personnel and representatives from the experiments, to discuss management issues, technical progress, schedule and cost issues throughout the life of the project. Other invitees include representatives from the RSVP Project Office and the DOE Brookhaven Area Office.

2.4 Management during operations phase

RSVP will be scheduled to run concurrent with RHIC operations and outside of RHIC operations. The present C-AD planning meetings relevant to RHIC operations are listed below.

1. Monday "Schedule Meeting" between RHIC experiment representatives, RHIC run coordinator, and C-AD Experiment and Accelerator Division Heads and Scheduling Physicist to discuss/fix the schedule for the upcoming week. Chaired by the Scheduling Physicist

2. Tuesday "Time Meeting" of BNL personnel (key engineers, physicists, MCR operations personnel, C-AD management, Associate Lab Director for HE&NP, experimenters and others are held during RHIC operations to discuss the schedule of collider operations (as well as AGS fixed target operations, if applicable), luminosity issues, any special problems operations personnel or experimenters may have etc. Chaired by the Scheduling Physicist.

3. Wednesday "RHIC Machine/Detector Planning Meeting" with experiments, attended by ALD for HE&NP, C-AD Department head, C-AD Division heads, RHIC Computing Facility representative, experiment spokespersons and others. Chaired by P. Pile

4. Daily (as needed) "RHIC Machine Status Accelerator Physicist Meeting" - accomplishments/problems of the previous 24 hrs, plan for next 24 hrs, experiment representatives are welcomed. Chaired by Accelerator Run Coordinator

These meetings are expected to continue into the RSVP era. The plan is to integrate key RSVP personnel into the RHIC planning meetings so they become participants in the scheduling and priority setting process.

As will be the case during the RSVP construction phase, RHIC operational needs will take priority over RSVP.

Details of the AGS Project Management Plan are contained elsewhere in the RSVP Project Management Plan

3. The AGS modifications

The AGS modifications for RSVP can be divided up into four basic categories. First are the modifications to the Booster and AGS that will ensure that RSVP operations do not compromise the operation of RHIC. Second modifications that are required to ensure compliance with laboratory environmental protection guidelines. Third modifications that are required to resume clean operations with high intensity. Finally modifications that are required to meet the RSVP experimental specifications.

3.1 RHIC Required Modifications

The high intensity proton beam has sufficient power to cause physical damage to accelerator components in the Booster and the AGS. A number of areas to which damage to components will affect RHIC operations have been identified.

During Booster injection and acceleration the beam has the potential of damaging the heavy ion inflector septum located in the C3 straight section of the Booster ring. A protection system will be added to prevent this from occurring. Also Booster injection beam losses cause radiation damage to magnet coil insulation, eventually resulting in magnet shorts. To remedy this carbon blocks are being added to specific areas in the injection region to absorb and diffuse beam losses in those areas. In addition collimation is being added to the injection transfer line to reduce beam losses in the injection region.

Losses during acceleration will damage magnet coil insulation in both the Booster and AGS. To some level this damage is predictable. We know where losses occur. But predicting which magnets will fail is difficult. To ensure we are prepared for magnet failures we will be purchasing spare magnet coils to have in hand if and when a failure occurs. Experience during the 1980's and 1990's tells us that we should expect about one magnet repair per year for both the Booster and the AGS during high intensity operations.

There exists a single spare unit for the Booster extraction septum magnet, known as the F6 septum. This magnet is very difficult to replace, and out of 5 replacements that have been done in the past, 3 resulted in the spare unit becoming shorted requiring immediate repair. This increased the occupational dose to workers and extended the repair period. A second spare magnet will be built prior to high intensity operation.

3.2 Modifications for Environmental Protection

New policies at BNL require that groundwater activation cannot exceed 5 % of the EPA drinking water limit. In order to meet this requirement we must put water impervious covers, called caps, over the soil-shielding covering the accelerator tunnels. The cost for these caps is borne entirely by RSVP, since the RHIC and NASA operations do not produce significant enough radiation, except at the dump that is already capped, to exceed the 5% limit. High intensity proton operations do produce significant radiation in all soil-shielded areas of the Booster Ring, and calculations show that the amount of beam loss required to exceed the 5 % level is not detectable, and therefore avoidable, with existing instrumentation. Therefore all shielding covering the Booster and AGS tunnels will have caps installed.

3.3 Modifications to Restore High Intensity Proton Operations in the AGS

The Booster and AGS have not operated for high intensity since 2002. The next anticipated high intensity operation is not until 2010. To ensure that the AGS will be capable of achieving beam intensities comparable to those achieved in 2002 a number of systems are required to be repaired and/or upgraded. Systems that fall under this category of modifications are the Booster loss

monitors system, the Booster extraction kicker pulse forming network (PFN), AGS injection kicker PFN, controls systems, AGS RC networks and ring grounds systems, AGS sextupole coils, motion systems, AGS loss monitors, and video systems.

The AGS extraction system will be redesigned for RSVP needs. The current extraction devices are ageing and require significant maintenance. Although RSVP demands require we design and build new magnets and power supplies, the age and condition of the exiting systems merit this be done independently, even were we only to return to the operational levels of 2002.

3.4 RSVP Specific Modifications

In order to achieve the RSVP program goals a number of systems need to be added or modified in the Booster and AGS. The goals are listed in Table 1. KOPIO requires a 25 MHz bunch structure on the slow extracted beam, which will be accomplished by the addition of a 25 MHz RF cavity, built in collaboration with TRIUMF. To achieve the 200 psec bunch widths a 100 MHz RF cavity may be required. To achieve the 100×10^{12} protons/cycle requires the intensity upgrades to the Booster and AGS. MECO requires a lower frequency bunch structure, which can be accomplished via the exiting RF systems in the AGS. To achieve the extinction level of 10^{-9} will require a gap cleaning system to be installed in the AGS. This system will be composed of an AC dipole and a series of strip-line kickers in the AGS. The high throughput beam intensity for MECO requires the intensity upgrades to the Booster and the AGS. The two main intensity upgrades consist of RF feedback in the Booster RF systems, to gain high stability and improve the capture efficiency during injection and the addition of kicker modules to AGS injection to allow an increase in the transfer beam energy from the Booster to the AGS. This will reduce the space charge effects seen during injection in the AGS, and will allow the beam to be kicked unto the equilibrium orbit during injection, thereby reducing losses.

Since MECO is a much lower beam energy extraction for the AGS, the aperture of the extraction magnets is not sufficient to allow efficient slow extraction. New extraction magnets need to be designed to accommodate the larger beam for MECO. The same magnets are required for KOPIO and so new power supplies are required, since the new magnets will require higher currents to achieve the magnetic fields required for KOPIO extraction.

Some beam studies have been performed that provide the proof of principle for the extraction systems for both experiments. These studies will be described in more detail in section 4. Additional beam studies have even been performed in order to explore some of the parameters for the KOPIO experiment. But to better understand the extraction processes and the best ways to optimize the parameters for the two experiments a significant amount of simulations work needs to be done. The simulations need to explore the parameter goals of the two experiments, and to understand high intensity and space charge effects on the experiment parameters and on the accelerator performance.

Both RSVP experiments have demanding beam requirements. Table 1 summarises the RSVP targeted performance goals along with the nominal operating parameters for slow extracted beam from the AGS. To meet these goals C-AD has evaluated all the systems required for high intensity protons operations and identified those systems that require updating and repair.

The operational goal is to run the MECO experiment at a sustained beam intensity of 20 TP/s. We are working towards raising this target to 40 TP/s. The actual spill length for KOPIO will be determined once rates are known and experiment optimization is completed. For planning purposes we should make sure the target design is good to 30TP/sec (50% above the present K0PI0 design specifications). Table 2 shows and operational scenario for the RSVP experiments.

Table 1. RSVP operational beam parameters

	Normal SEB	KOPIO	MECO
P (GeV/c)	25.5	25.5	7.5
Rep. Time (sec)	5.3	7.18	1
Spill Length (sec)	3	4.88	0.5
Intensity	> 70 TP/pulse	100 TP/pulse	20 TP/pulse, 2 bunches
Bunch length	DC	200 psec (goal) 260 (w/o 100 MHz)	~10 nsec
Time between bunche	DC	40 nsec	1.35 usec
dp/p (%)	0.7 - 0.9	< 0.5	~ 1.0
Int. Intensity (# protons)	$7x10^{20}$ (post-Booster sum)	$9x10^{20}$	$2x10^{20}$
Extinction	NA	10^{-3}	10^{-9}

Table 2. An Illustrative Scenario for RSVP Running

Fiscal Year	Running Activity	Duration (weeks)	Begin (end) intensity	Hours of running
2010	Pre-operations: KOPIO neutral beam, MECO extinction	8	As high as possible	640
2011	KOPIO Engineering	5	10 (30) TP/pulse	400
2011	KOPIO Operations	20	30 (75) TP/p	2000
2012	MECO Engineering	5	2 (10) TP/second	400
2012	MECO Operations	20	10 (17.5) TP/s	2000
2013	KOPIO Operations	25	75 (100) TP/p	2240
2014	MECO Operations	25	17.5 (20) TP/s	2240
2015	KOPIO Operations	25	100 TP/p	2240
2016	MECO Operations	25	20 TP/s	2240
TOTALS:				
8 WEEKS PRE-OPERATIONS				
10 WEEKS ENGINEERING				
12960 TOTAL HOURS OPERATIONS				

4. Timelines and Milestones

The two charts below show the BNL/AGS-RSVP project Timelines and Milestones for the AGS and Switchyard modification and the KOPIO and MECO beam lines and experiment construction taken from the project Work Breakdown Structure.
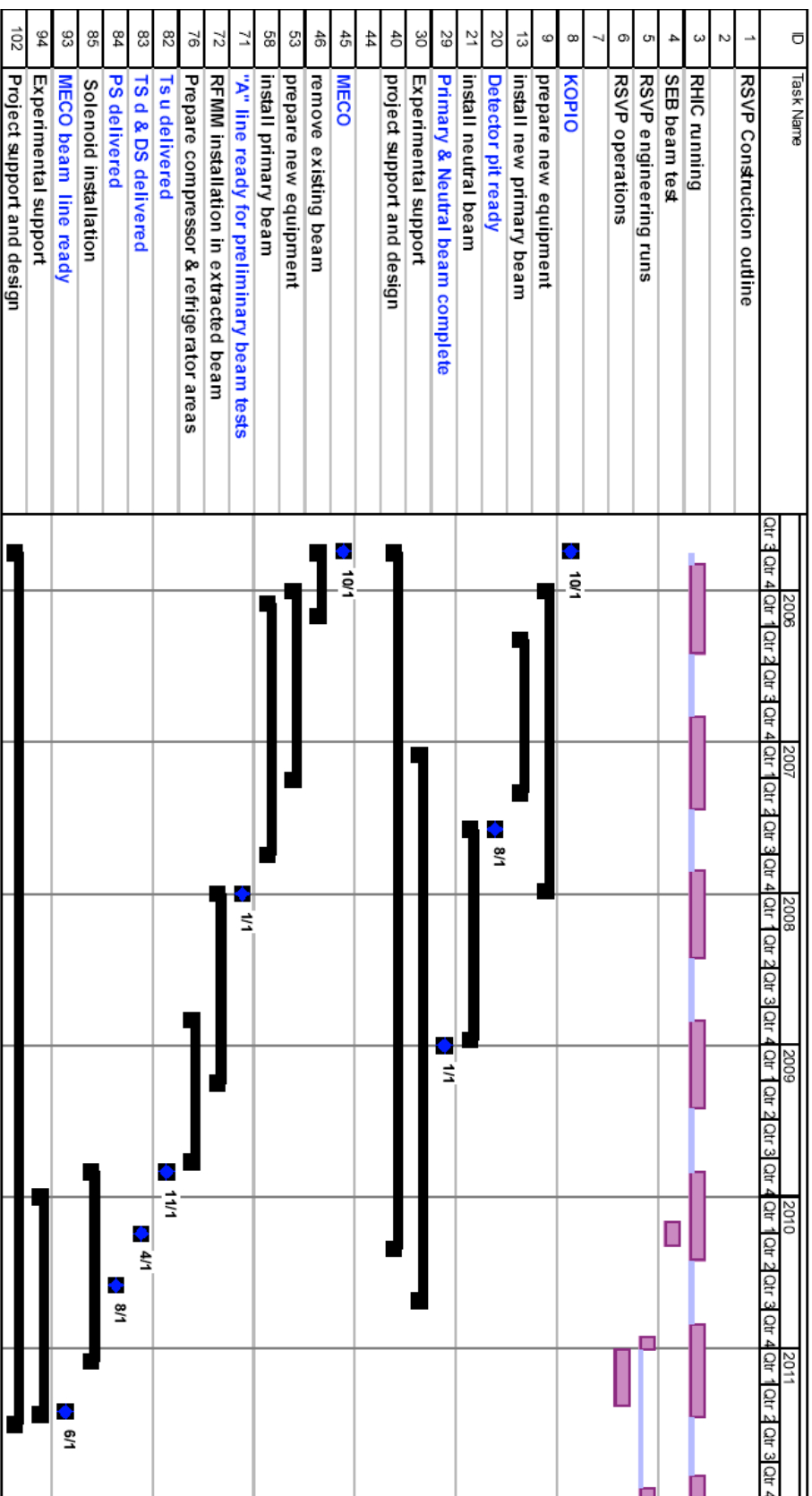
Timeline and milestones for the KOPIO and MECO beam lines construction and experiment installation

ID	Task Name
109	RHIC running
110	SEB beam test
111	RSVP engineering runs
112	RSVP operations
113	
114	
115	Switchyard Modifications
129	remove existing beams
131	Project support and design
135	SYG / AGS radiation plug installed
136	SYG ready
137	
138	Booster Modifications
145	
146	AGS Modifications
147	AGS ALARA improvements
155	AC dipole/strip line kicker upgrade
159	AC dipole & strip line kickers ready
160	A-10 kicker upgrade
164	A-10 kicker ready
165	Extraction system upgrade
172	New extraction system ready
173	RF upgrades
178	25Mz RF cavity ready
179	100Mz cavity ready
180	AGS / Booster support & design

Timeline columns: 2006 (Qtr 3, Qtr 4), 2007 (Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2008 (Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2009 (Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2010 (Qtr 1, Qtr 2, Qtr 3, Qtr 4), 2011 (Qtr 1, Qtr 2, Qtr 3, Qtr 4)

Milestone markers: 10/1, 11/1, 11/1, 12/1, 9/1, 8/1, 9/1

Timeline and milestones for the RSVP Booster, AGS, and Switchyard modifications

Chapter II: Technical details of the performance and proposed modifications

1. Booster and AGS Description

The AGS has a long history of providing high quality slow extracted beams to fixed target experiments. It is the only high energy accelerator in the world to achieve beam intensities over 70×10^{12} protons/cycle. The AGS Booster began operations in 1991 and has since been the injector for the AGS.

Table 1: Booster and AGS Parameters

Parameter	Booster	AGS
Circumference	201.78 (1/4 AGS) m	807.094 m
Ave. Radius	32.114 m	128.453 m
Bend Radius	13.8656 m	85.3785 m
Lattice Type	Separated Function, FODO	Combined Function, FOFO
No. Super periods	6	12
Betatron Tune X,Y	4.82, 4.83	8.72, 8.80
Vacuum Chamber	70 x 120 mm Dipoles 152 mm (circular) Quads	78 x 173 mm Dipoles
Max. Rigidity	17 Tm	110 Tm
Injection Rigidity	2.2 Tm (200 MeV protons)	9.076 Tm (1.94 GeV protons)
Acceleration Rate	8.9 T/s	2.5 T/s

The AGS Booster accepts ions from the Tandem Van de Graff and polarized protons and high intensity protons from the 200 MeV LINAC. The AGS Booster is a high vacuum rapid cycling accelerator used to fill the AGS with ions and/or protons (1.94 GeV) and to slow extract ions to NSRL (1 GeV/n ions). The AGS accepts ions, polarized protons, and high intensity protons from the Booster and through fast extraction is used to fill RHIC with ions and/or polarized protons. It can also slow extract ions and high intensity protons to fixed target experiments. Table 1 gives a summary of the parameters for the Booster and the AGS. Figure 1 shows the layout of the Booster along with the components of interest for RSVP.
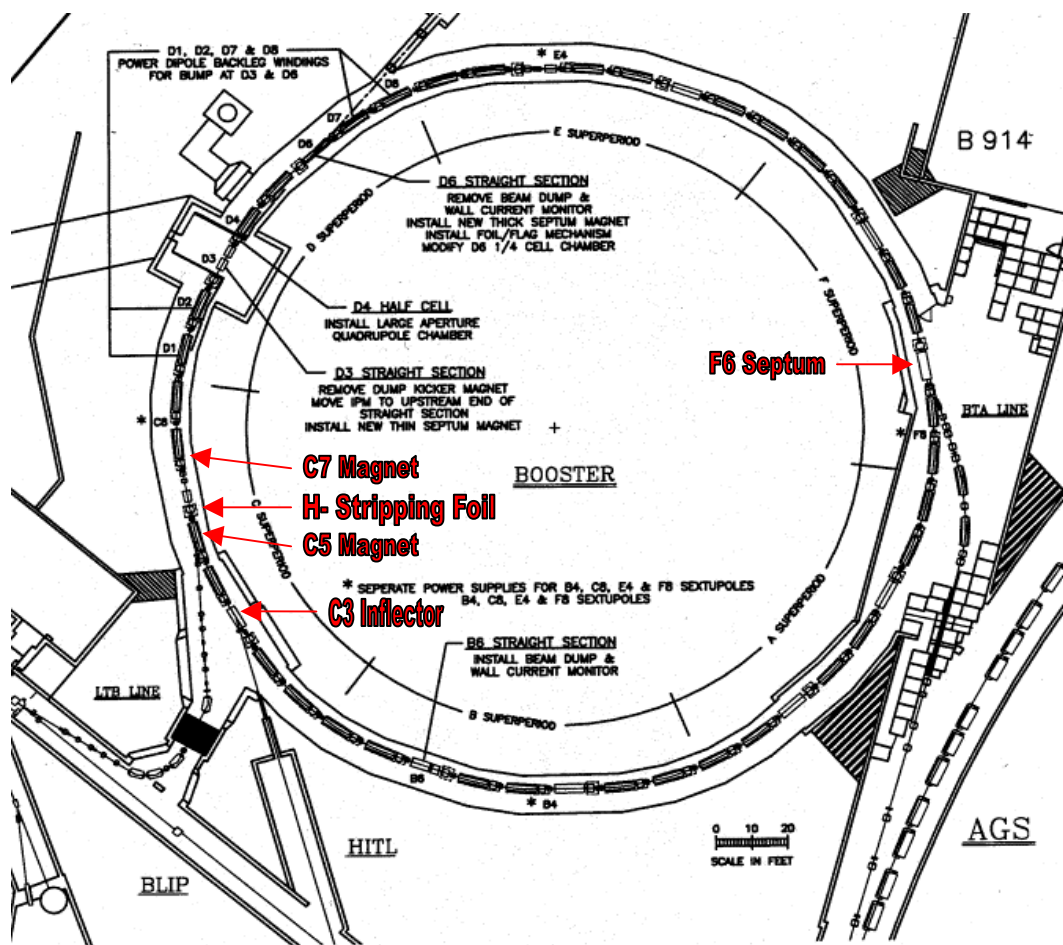
Figure 1. Booster schematic indicating the locations of the RSVP modifications.

1.1 Booster/AGS Performance

For normal slow extracted beam (SEB) operation with a 5.4 second AGS cycle time and 6 Booster fills per AGS cycle, the peak throughput achieved was 19.6 Tp/sec, (1 TP = 1×10^{12} protons) Booster Late and 13.7 Tp/sec, AGS Late. The peak intensity for SEB operation was 73 TP/cycle. Table 2 shows the 10 pulse best performance data from the 2002 SEB run.

Table 2: SEB 10 Pulse Ave. Data (best performance)

	Intensity (Tp/cycle)*	Efficiency (%)	Beam Loss (Tp/cycle)	ALARA (Tp/cycle)	Loss (kW)	Loss/m (W/m)
Linac	177	-	-	-	-	
Booster Injected	125	71	52	54	0.31	1.5
Booster Extracted	106	86	18	18	0.5	2.5
AGS Injected	78	74	28	31.5	1.62	2.0**
Transition	76	98	2	3	0.26	0.3
After Transition	73	95	3	4.5	0.63	0.8
AGS Late	73	100	0	1.5	0	0

** assumed lost in the AGS

For normal fast extracted beam (FEB) operation with a 2.77 sec. AGS cycle time and 6 Booster cycles fills per AGS cycle, the peak throughput achieved was 30 Tp/sec, Booster Late and 22 Tp/sec, AGS Late. The peak intensity for FEB operation was 61.4 TP/cycle. Table 3 shows the 10 pulse best performance data from the 2001 FEB run.

Table 3: FEB 10 Pulse Ave. Data (best performance, not sustainable operation)

	Intensity (Tp/cycle)	Efficiency (%)	Beam Loss (Tp/cycle)	ALARA (Tp/cycle)	Loss (kW)	Loss/m (W/m)
Linac	115	-	-	-	-	-
Booster Injected	89	77	27	27.7	0.31	1.5
Booster Extracted	83	93	6	9.2	0.33	1.6
AGS Injected	66	78	18	16.3	2.0	2.5**
Before Transition	62.3	94	3.7	1.5	0.9	1.1
After Transition	61.6	99	0.6	2.3	0.2	0.2
AGS Late	61.4	99.5	0.3	0.8	0.25	0.3

** assumed lost in the AGS

As can be seen in tables 2 and 3 the beam losses at different times in the cycle can be significant during high intensity operation. These losses are administratively managed to keep radiation dose to workers to as low as reasonably achievable (ALARA) and for these workers to still be able to maintain the accelerator.

1.2 Slow Extraction from the AGS

Slow extraction from a synchrotron refers to the deliberate excitation of a betatron resonance so that transverse oscillation amplitudes of charged particles cross into the acceptance of an extraction septum. When the motion of particles falling into resonance is strongly influenced by their longitudinal momentum, extraction is referred to as *chromatic*. Slow extraction from the AGS is a chromatic slow extraction that exploits a sextupole driven resonance to excite the

particle transverse amplitudes. Four sextupoles are used to create the resonance. To extract the beam in resonance, three septa devices are utilized; a very thin electrostatic septum (H20), a thin magnetic septum (F5), and a thick magnetic septum (F10). The three septa need to be precisely aligned to minimize losses during the extraction process. Two orbit deformations are created to distort the equilibrium orbit around the septa, ensuring that no other aperture in the accelerator can shadow the septa devices. Figure 2 shows a schematic view of the AGS slow extraction system.
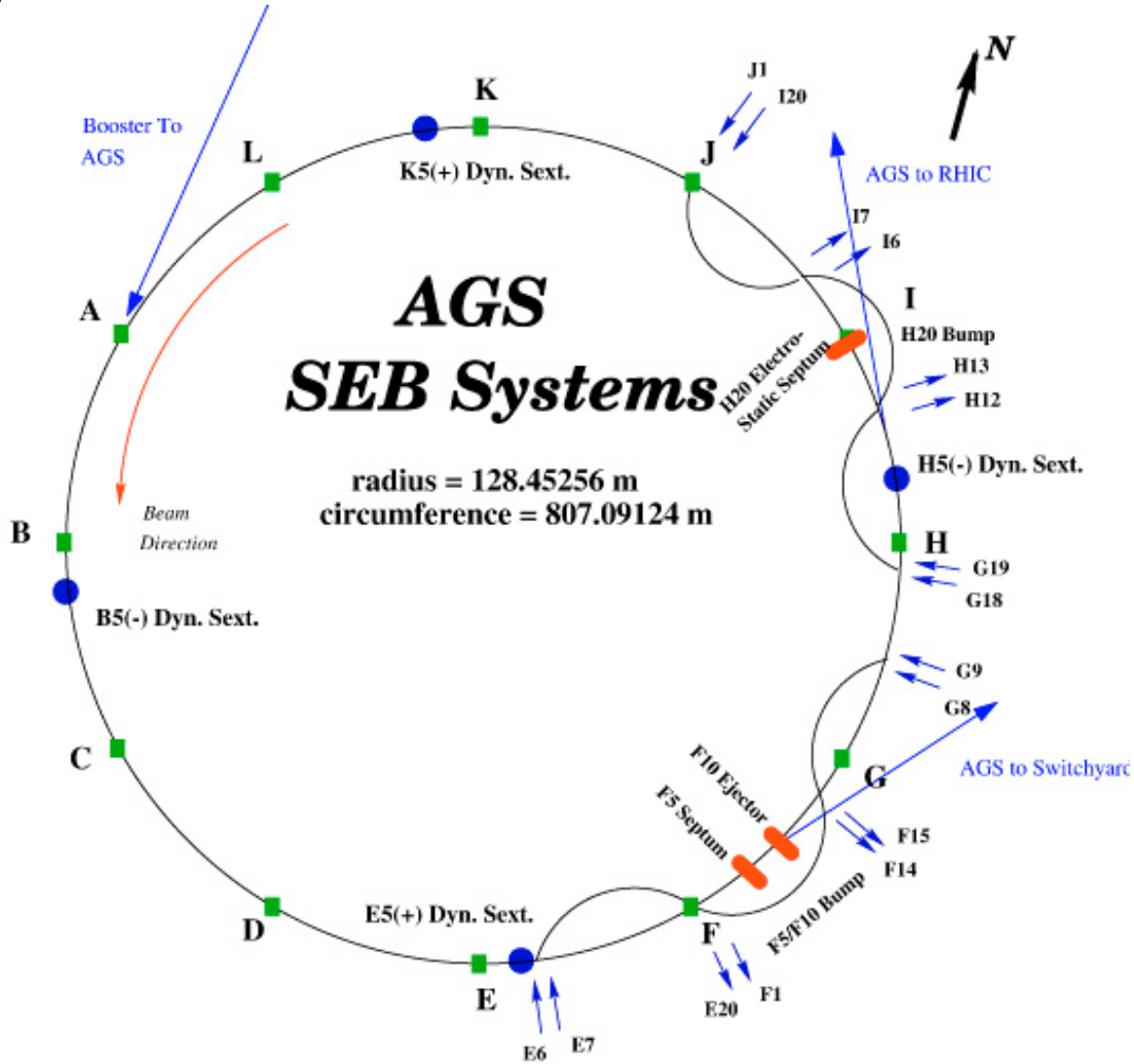
Figure 2. The AGS Slow Extraction Systems

The AGS Resonant extraction system and the beam transport and switchyard systems were designed in the pre-AGS Booster era, when the kinetic energy of the injected beam was 200 MeV. In the post-Booster era, which began in 1991, this energy is now 1.94 GeV. For these two energies the ratio of $\beta\gamma$ is approximately 3.5. Therefore the maximum possible beam emittance is over 3.5 times larger for post-Booster high intensity beams. Even though the emittance is larger, through careful measurements and simulations we have been able to find optics solutions that

allow clean extraction and transport of these high intensity beams for normal high energy slow extraction. The measured beam emittances for high intensity protons, made in 1996, are $\varepsilon_h^{99\%,N} = 98\ \pi$ mm-mrad and $\varepsilon_v^{99\%,N} = 85\ \pi$ mm-mrad. Table 4 lists normal SEB performance parameters.

The extraction efficiency, at lower intensity operation (below 50 TP), is usually very close to 98%. At higher intensities we have observed a slight degradation, to 97.5%, which is apparently due to transverse instabilities causing some vertical beam blowup.

We use a 93 MHz RF cavity to correct low frequency spill structure by employing RF phase displacement, which accelerates particles through the resonance, reducing the effect of variations in the passage through the resonance and creating a more uniform in time beam distribution. At high intensity it has been observed that this degrades the extraction efficiency slightly, to about 97 %. This additional 0.5% in beam loss gets dumped into the AGS beam dump at the end of the flattop.

Transport efficiencies are a function of the beam splitting in the switchyard. At high energy, with no beam splits the efficiency is typically better than 95%. Most of the losses are in the area of the beam splitters (which are limiting apertures for the existing switchyard), even for no beam splits, and on the associated Lambertson magnets.

Table 4: AGS SEB Performance Parameters

Parameter	Value	Units
Momentum	25.5	GeV/c
Extract. Eff.	96-98	%
Transport Eff.	90-95	%
Rep. Period	4-8	second
Flattop Length	2-6	second
Spill Length	1.8-5.8	second
Working Point	8.67/8.76	Tune (*vx, vy*)
Chromaticity	-2.3/0.2	Chrom.($\xi x, \xi y$)

2.0 Booster Modifications

Modifications to the AGS Booster for RSVP will ensure operation for RSVP without impact to either RHIC or NSRL.

2.1 Conventional Infrastructure

Tunnels, buildings, services and access points exist and are already maintained under existing contracts. The only area of concern is ageing cable trays in the tunnels. These are explicitly identified in the WBS. Infrastructure upgrade components include: identified damage to cables trays, and work to be performed in and around the cable trays. A safety review of this work must identify whether the trays are safe.

2.2 Electrical Modifications

A number of areas were identified where cables are getting old and brittle, or have suffered either radiation or mechanical damage. These cables would be repaired, replaced or removed if they are no longer in use in advance of running high intensity as further activation during high intensity operations will accelerate the failure rates in the cables. They also pose hazards to C-AD personnel who may have to work on or near the cables. Additionally, the radiation burden to workers will be unacceptable if they have to do cable repair in areas that have high levels of residual radioactivity following high-intensity running periods. It is important to note that damaged cables pose an unacceptable risk of fire and electrocution either of which result in a significant programmatic impact.

A number of magnet coils have become damaged over the years and C-AD managers have determined that a failure rate of one magnet per year is to be expected during high intensity operations. In order to be prepared for this we plan to purchase additional coil sets during the construction phase. Included in the construction cost estimate is the cost to replace one set of coils. During RSVP operations we expect to repair one magnet per year. If this is not done then further activation from high intensity protons will increase the risk that a magnet will fail during operations. This has the potential of adversely affecting RHIC and NASA operations. With spare parts on hand to repair a shorted magnet, then the estimated repair time is at least one week (longer if it requires cool-down time). If we don't have the parts for the repair (e.g., magnet coils), then it could result in a three to six month shutdown to allow requisition of the parts, testing and installation.

The pulse forming networks (PFN's) for the Booster F3 extraction kicker power supply and associated capacitor bank have received significant radiation dose over many years of operation and are in need of replacement. Included in the WBS is a redesign of the capacitor banks, to reduce radiation damage in future high intensity operations, and to replace ageing and radiation damaged components. If not done then further activation from high intensity protons will increase the risk that the charging system for the extraction kicker will fail during operations. The extraction kicker is required for RHIC operations. The impact on the operating schedule is significant, since a repair will require at least one week, without cool-down time, and many months if we have to requisition parts.

2.3 Mechanical Modifications

A critical component to the operation of any RHIC or AGS program is the Booster extraction septum magnet (F6). A spare magnet is included in the RSVP WBS. RHIC operations will not significantly activate this magnet. If this work is not done then the anticipated activation from high intensity protons will increase the risk of a magnet failure and would adversely affect RHIC and NASA operations, as well as RSVP.
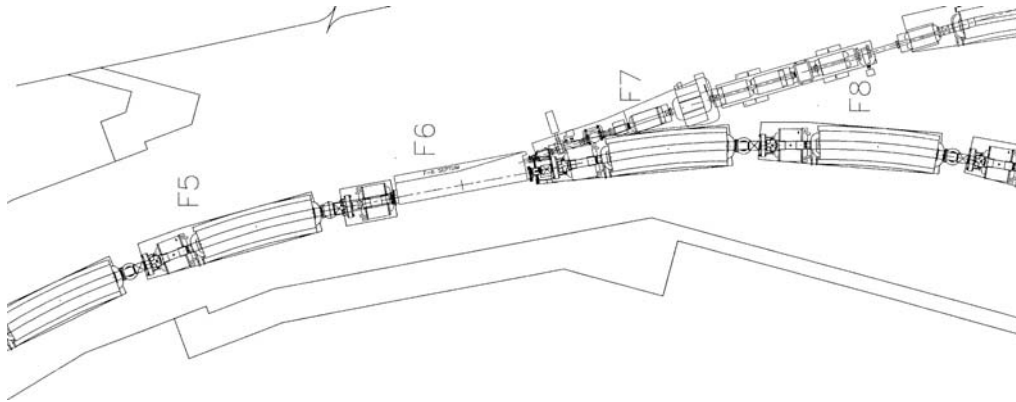
Figure 3. F6 location in the Booster.

Beam losses at Booster injection are the most significant source of residual activation in the Booster. A particular problem is activation due to the beam scraping and associated stripping of the H$^-$ beam that is injected before the H$^-$ stripping foil. This has led to the failure of the Booster main dipole at C5, which is a special design for proton injection with a hole bored through the side laminations to allow the H$^-$ beam to enter from the transfer line. In addition the foil stripping of H$^-$ to H$^+$, which occurs in the upstream section of the C6 straight section, is not 100% efficient. The fraction of the H$^-$ beam that misses the foil ends up in the C7 main dipole. This magnet was replaced after it developed a short to ground in 1998. Methods to reduce this activation include adding collimation in the transfer line to prevent beam scrapping at the entrance of the C5 magnet and to prevent the H$^-$ beam from missing the stripping foil. The addition of carbon blocks between the vacuum chamber and the magnet coils in the C5 and C7 magnets will help diffuse and absorb lost particles.
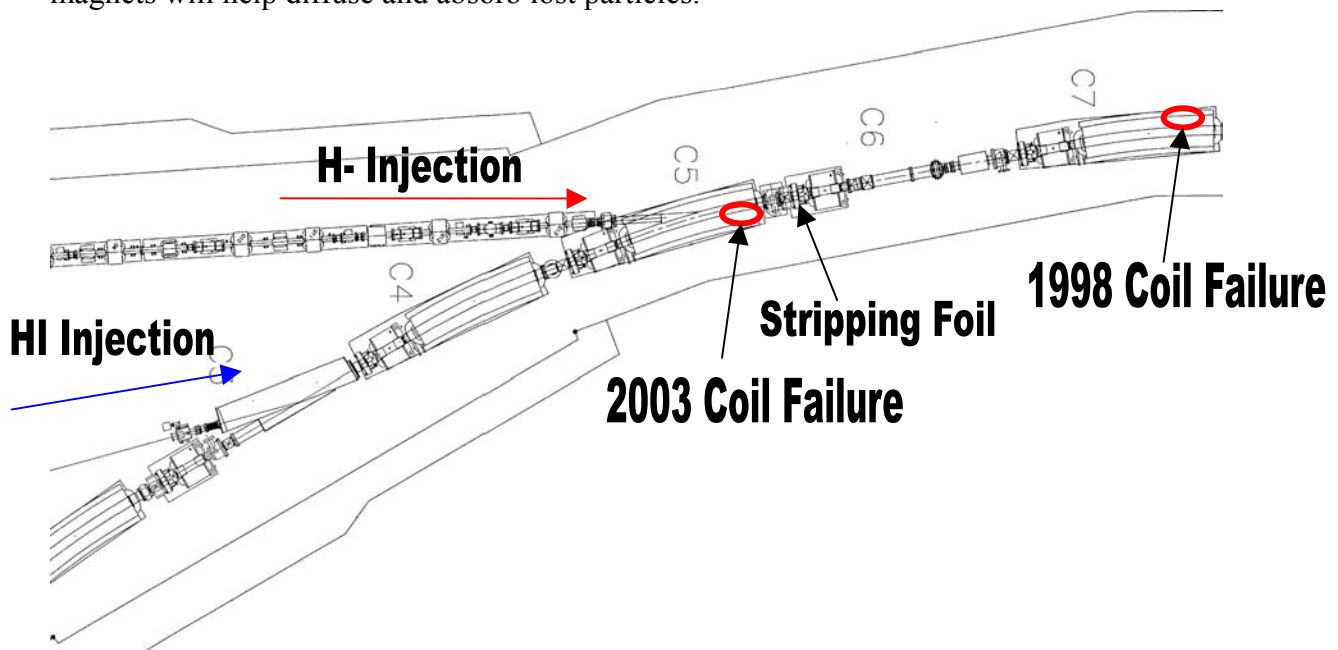

Figure 4. The injection region in the Booster. The Red arrow shows where H$^-$ is injected.

2.4 RF Modifications

To improve the operation of the RF and allow for multiple modes of operation, the Band III RF cavities were modified with RF fast feedback. This feedback allows the RF system to compensate for high intensity and operate with greater stability. Adding RF feedback to the Band II cavities is included in the WBS. For high intensity operation both systems are in use thus further modifications of the Band III system are required as beam loading becomes significant. This is in an important item for RSVP operations and will improve the stability of the beam intensities and may allow higher intensities to be achieved. This work must be done, although it will not impact RHIC or NASA operations, since the current state of the Booster RF system cannot support the high intensity protons operation called for RSVP.

2.5 Instrumentation

There are a number of issues related to the instrumentation in the Booster.

1)   The Booster loss monitor system is old, has become extremely unreliable, and needs repair and upgrading. Included here is replacement of old gas lines and a new data acquisition system. While this is not required for RHIC or NASA operations. It is a critical system that is required for high intensity operations, since it is used to alarm on high losses and defines thresholds for ALARA limits.

2)   There are two wall current monitors in the Booster. One is used exclusively for the RF system to provide a reference for the phase loops. The other is available for measurements. The new wall monitor added in FY03 was designed for high intensity, but suffers from a frequency response problem. A new design is required as well as data acquisition. Similarly this is not required for RHIC or NASA operations. It is crucial for high intensity operations, since the frequency response problem prevents resolving high frequency instabilities with the high intensity beams. This system was cut out of the main project during cost cutting exercises.

3)   The C3 inflector is used to inject heavy ions into the Booster, figure 4 above. In October 2003 it was found that the septum of the inflector was distorted, figure 5. Historically it was necessary to operate with a vertical offset of the heavy ion beams during injection. After repairing the septum it was no longer necessary to operate with the vertical offset. Protecting the septum from the high intensity proton beams is required. A protection system will be designed and built. This particular item is important as it has the potential of seriously affecting RHIC and NASA operations.
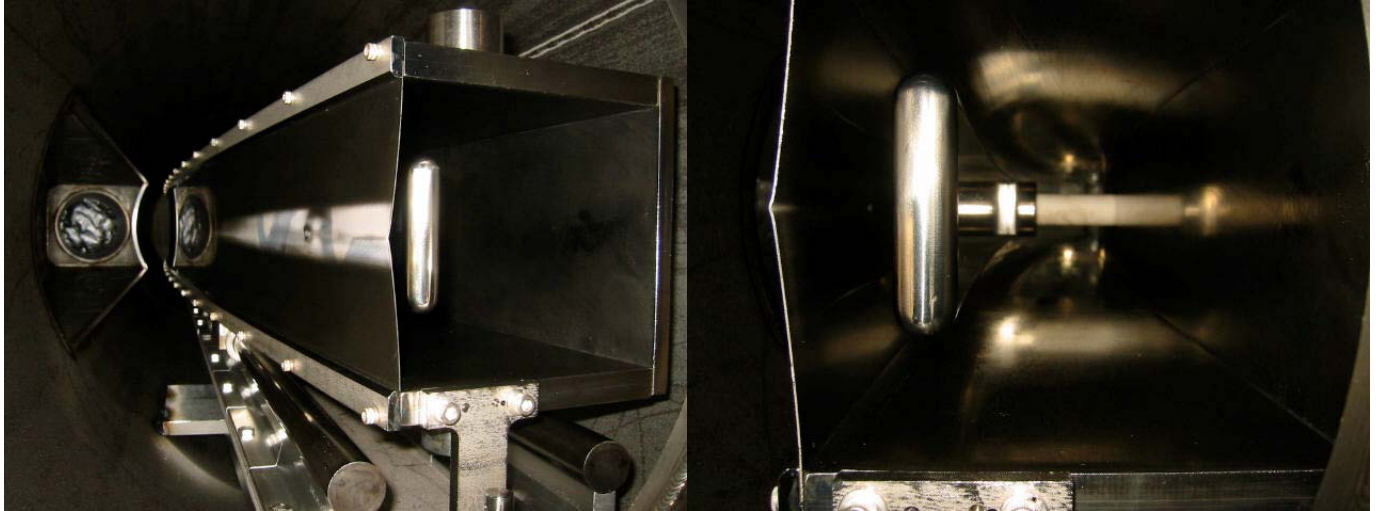
Figure 5. Photographs of the damaged C3 inflector (the "folded" sheet should be flat).

4) Repair/replacement of radiation damaged or old instrumentation cables needs to carried our prior to the high intensity running in order not to increase their activation and accelerate failure rates in the cables. They pose a fire hazard and pose an electrocution hazard to C-AD personnel who may have to work on or near the cables.

5) BTA instrumentation will have some modifications made to allow remote gain switching between heavy ions and high intensity protons. This is not required for the current RHIC or NASA operations. It will affect RSVP, since the ability to change gains remotely will provide a faster setup of the Booster to AGS transfer line with high intensity protons during RHIC or NASA operations. This system was cut out of the main project during cost cutting exercises.

2.6 Controls

The following controls items must be addressed to ensure maintainable delivery of high intensity protons. This is detailed in a later chapter.

1) Standard VME interfaces will be provided for the instrumentation systems listed above, replacing un-maintainable legacy controls hardware.

2) Software and database engineering will be needed for both new front-end interfaces and console level applications.

3. AGS Modifications

Modifications to the AGS for RSVP will ensure high intensity proton operation for RSVP without impact to RHIC.

3.1 Conventional Infrastructure

Similar to the Booster above, the AGS tunnels, buildings, services and access points exist and are already maintained under existing contracts. The only area of concern is ageing cable trays in the tunnels. These are explicitly identified in the WBS. Infrastructure upgrade components include: identified damage to cables trays, and work to be performed in and around the cable trays. A safety review of this work must identify whether the trays are safe. We must include in our contingency the possibility of supporting further repair and/or upgrade of portions of the cable tray systems.

3.2 Electrical

There are a number of areas where cables are getting old and brittle, or have become radiation damaged or damaged in other ways. These cables would be repaired or replaced or removed if they are no longer in use in advance of running high intensity. If this work is not done before high intensity running then there is much greater risk that further activation during high intensity operations will accelerate failure rates in the cables. They also pose hazards to C-AD personnel who may have to work on or near the cables. Additionally, the radiation burden to workers will be unacceptable if they have to do cable repair in areas that have high levels of residual radioactivity following high-intensity running periods. It is important to note that damaged cables pose the risk of fire and electrocution. A fire could have a significant programmatic impact and potential for electrocution is an unacceptable risk.

There are a number of magnet coils which have become damaged over the years and C-AD managers have identified a set of magnets which have received the highest beam losses and would have coils replaced in advance to running high intensity. If this is not done then further activation from high intensity protons will increase the risk that the magnet will fail during operations. This has the potential of adversely affecting RHIC and NASA operations.

The AGS Main Magnet ripple has been evaluated and the plan for improving it requires a new active filter power supply. Ripple structure on the slow extracted beam needs to be minimized in order to keep individual bunch intensities for both RSVP experiments as uniform as possible. In addition, the dynamics of the slow extraction process for bunched and micro-bunched slow extraction are such that bunch widths and extinction rates have dependencies on the amount of ripple structure seen by the beam. This system was removed from the project during the cost cutting exercise, with the knowledge that it would impact RSVP performance.

The F5 (thin) and F10 (thick) septa are critical components for slow extraction for RSVP. New low ripple power supplies for the new magnets are included. If this is not done it will seriously affect RSVP operations since the risk of failure using the existing supplies (assuming they could be made compatible with the new magnets) is considered very high due to their age (>30 yrs) and current condition.

In the last slow extraction run we learned that the J10 beam dump bump power supply was a significant source of beam spill ripple. A new low-ripple power supply is included to eliminate this problem. If this is not done it will seriously affect RSVP operations since it has a significant

affect on the beam spill structure. This system was removed from the project during the cost cutting exercise, with the knowledge that it would impact RSVP performance.

The pulse forming networks (PFN's) for the AGS A5 injection kicker power supply and associated capacitor bank have received significant radiation dose over many years of operation and are in need of replacement. Included in the WBS is a redesign of the capacitor banks, to reduce radiation damage in future high intensity operation, and to replace aging and radiation damaged components. If this is not done then further activation from high intensity protons will increase the risk that the charging system for the extraction kicker will fail during operations. This is also an ALARA issue, since the best time to make these modifications is while the accelerators are not highly activated. The extraction kicker is required for RHIC operations. A failure of this system will have a significant impact on the operating schedule, since a repair will require at least one week, without cool-downtime, and many months if we have to requisition parts.

3.3 Mechanical

Critical components for RSVP are the extraction septa in the AGS. There are three devices used in the extraction process, a very thin electrostatic septum (F20), a thin magnet septum (F5), and a thick magnetic septum (F10). The existing devices are old, and do not have sufficient aperture for the high intensity RSVP beams (in particular for MECO, which is lower energy extraction). The replacement of these devices is considered an ALARA issue, since the existing devices are difficult to maintain. New designs will allow an easier and more efficient maintenance of these devices and a reduction in the radiation burden on workers. These devices can become significantly activated during high intensity slow extraction. It is best to start with new, non-activated devices.

The current electrostatic septum design may adversely affect the AGS impedance significantly, so part of the new design is to evaluate this and develop a design that has a minimal impact on the impedance. Figure 6 shows the current AGS septum and the septum used at CERN, which is our model for a new design. The AGS impedance is an important issue for high intensity operations since beam instabilities are a function of the impedance.

To make the acceptance of the electrostatic septum (H20) and the thick magnetic septum (F10) greater than 99 π mm-mrad for 8 GeV protons we require the following specifications shown in Table 5: (Currently F10 and H20 gaps are ~20 mm)

Table 5: New extraction septa parameters for RSVP

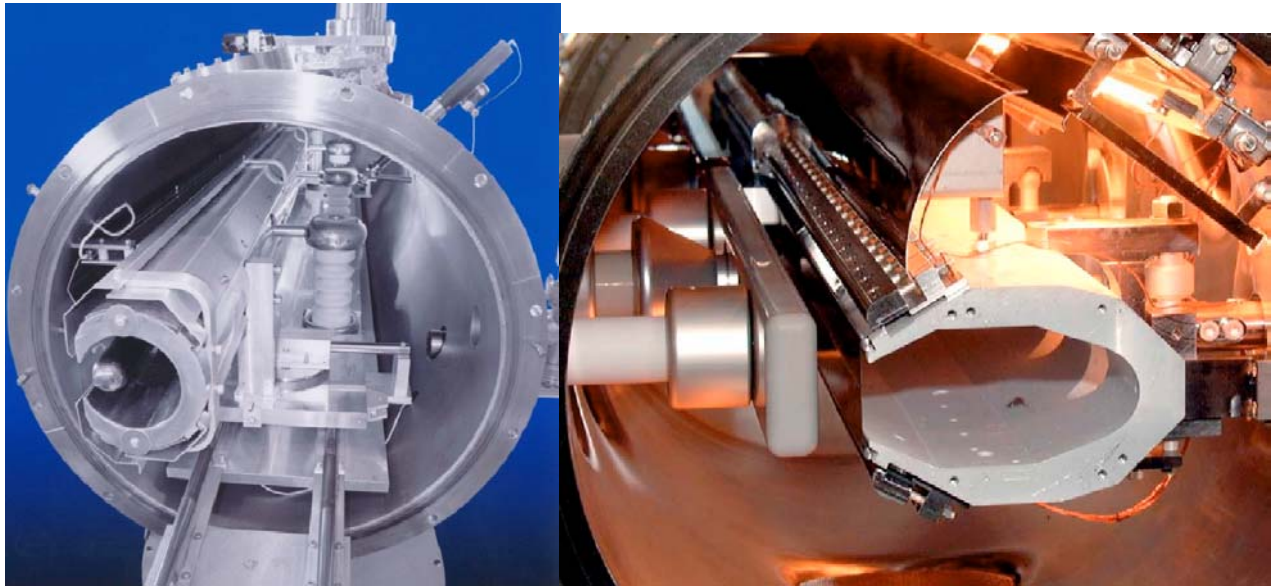|	F5	F10	H20
Horz. gap (mm)	44.45	38.1	10 - 20 (variable gap)
Vert. gap (mm)	22	30.4	30.4
Length (m)	0.667	0.81+1.22=2.03	2.3
Septum (mm)	0.76	13.5/15.85	0.05
Bend (mrad)	1.1	18.5	0.43
Field (max)	2.1 kG	14.4 kG	80 kV/cm

Figure 6. The AGS electrostatic septum (left) and CERN electrostatic septum (right).

A careful review of vacuum chamber grounds, insulation, and RC networks has been done and a plan has been developed to best reduce the impedances due to the vacuum chamber and to prevent beam/rf noise from radiating into other equipment. These issues are significant for high intensity running and could affect RSVP operations and potentially affect RHIC.

New coils are identified for the AGS sextupoles, which have not been replaced in over 40 years and cannot accept the higher currents required for developing higher intensity beams. In an existing improvement project 12 sextupole coils have been replaced. For this project, we would utilize this new coil design and replace 16 more coils in the AGS. For cost reductions, this system was moved into RSVP management contingency.

3.4 Instrumentation

There are a number of issues related to the instrumentation in the AGS.
1) The AGS long loss monitor system is becoming old and needs repair and upgrades. Included here is replacement of old gas lines and detectors, and new electronics. This system is critical for high intensity operations, since it is our primary monitor of extraction efficiency and is used for operations ALARA alarm monitoring.

2) There is one wall current monitor in the AGS. It historically suffers serious degradation problems during high intensity operation. A new design specifically for high power beams is included. The wall current monitor is a critical piece of instrumentation used to understand the longitudinal beam characteristics. Additionally, for observing beam instabilities associated with high intensity protons, a higher frequency (higher bandwidth, up to 1 GHz) wall current monitor is required. Not doing this work will impact our ability to diagnose high intensity phenomena. This system was cut out of the main project during cost cutting exercises.

3) Motion controls for flags and movable devices in the AGS ring are old and need to be replaced. This includes very old controls for the motors. While it does not affect RHIC or NASA operations, it will seriously affect RSVP.

4) RSVP needs 4 flags in the AGS which will require cameras that can withstand the high radiation environment. This upgrade is not required for RHIC or NASA operations.

5) Repair/replacement of radiation damaged or old cables. This is to be done prior to high intensity operations in order to avoid further activation which accelerates the failure rates in the cables. Damaged cables pose the risk of fire and electrocution.

6) AGS ring grounds monitoring system upgrade. Not doing this work will not affect RHIC or NASA operations. It will seriously affect RSVP.

3.5 Controls

The following controls items must be addressed to ensure maintainable delivery of high intensity proton beams. This is detailed in a later chapter.

1. Standard VME interfaces will be provided for the instrumentation systems for which existing legacy controls interfaces are un-maintainable.

2. Standard VME power supply interfaces will be provided for the H20, F5, and F10 septa power supplies.

3. Software and database engineering will be needed for both new front-end interfaces and console level applications.

Not doing this work will adversely affect RSVP operations, since maintaining legacy controls hardware that have unpredictable failure modes and poor documentation is extremely difficult.

4. Modifications for RSVP Experiments

4.1 Intensity Upgrades

Beam intensity is limited by a number of different factors. Each stage in the acceleration process, from the LINAC to the experiment has associated beam losses. In each area the details of the given process dictates the loss mechanisms. For example, during Booster injection beam has to be captured inside the RF momentum and phase acceptance (called an RF bucket) and there is an intrinsic RF capture beam loss during this process. At high intensity, space charge forces cause additional beam losses. Significant time is spent, during operations for high intensity, adjusting parameters to minimize these losses. As a result there exist fundamental limits on achievable beam intensities due to the amount of initial beam available from the ion source and as a result of

the transmission efficiencies at the various stages of the accelerators. The modifications in both the Booster and AGS for intensity are focused entirely on improving transmission efficiencies in the various stages of the accelerators. Another limitation to the beam intensity is the acceptable rate of the beam losses during a given operation period. The accelerators have to be maintainable by people and so the amount of activation of the accelerators is managed administratively to keep workers' occupational dose as low as reasonably achievable.

In the Booster, the RF capture process can be improved by providing RF feedback. This is illustrated in figure 7, which shows the stability of the RF during injection and capture. The figure shows the RF gap volts sum, with both the 1st and 2nd harmonic systems on. The horizontal scale spans 4 revolution periods. The vertical scale spans 100 consecutive sets of these 4 revolution periods. The RF feedback system would eliminate the variations in the phase of the RF sine waves.

Figure 7. RF gap volts sum. 1st and 2nd harmonic cavities at injection during RF capture.
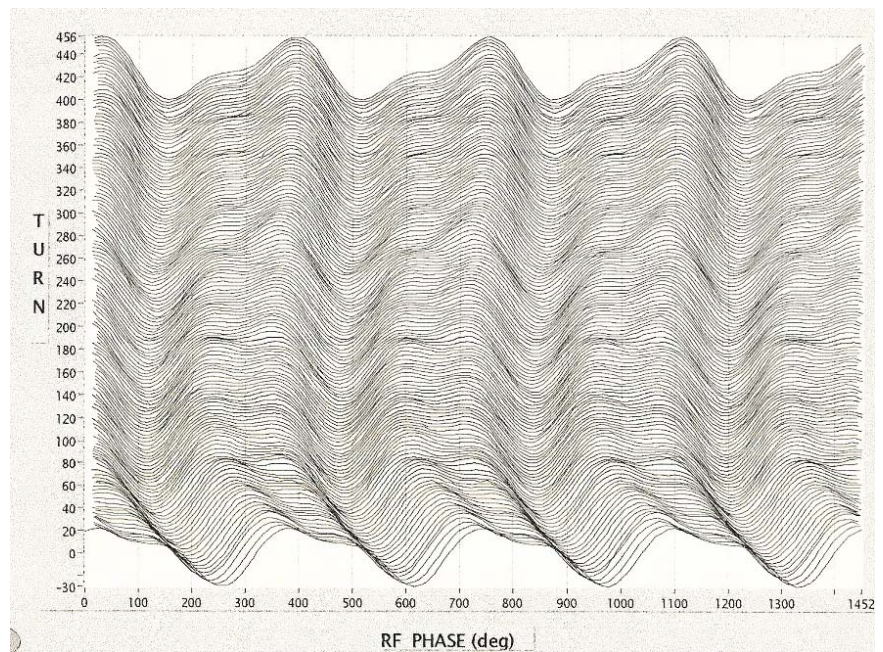
The largest increase in performance is expected to come from improvements in the transfer of beam from the Booster to the AGS. Currently the kicker magnet responsible for AGS injection is operating beyond its capabilities, causing losses in both the Booster and the AGS. The original design for the Booster to AGS transfer line was for 1.5 GeV. The goal of the AGS injection upgrades is to do the transfer at 2.0 GeV. We currently transfer beam from the Booster to the AGS at 1.94 GeV with an AGS injection mismatch, since the maximum rigidity that the A5 injection kicker is capable of corresponds to slightly higher than 1.5 GeV. The rest of the elements in the Booster to AGS transfer systems are capable of 2.0 GeV operation. This mismatch in apertures reduces the transfer efficiency due to the inability of the kicker magnet to get the beam into a stable orbit in the AGS. Upgrading the A5 kicker system and increasing the injection energy will allow higher beam currents to be maintained with lower beam losses. Because the AGS is operating in a mode where it is very nearly limited by radiation losses, improving the beam transfer is a crucial step in increasing the beam intensity.

The upgrade to the AGS injection system consists of adding two more kicker modules into the A10 straight section in the AGS. This work is being done in collaboration with TRIUMF, who will supply the A10 kicker magnets, PFNs, and power supplies. TRIUMF is responsible for providing the new HV portion including the Transmission Line kicker magnet and vacuum enclosure, HVPS, Thyratrons and switch assembly, optically isolated thyratron grid drive circuits, PFL cables, HV transmission cables, terminating resistors, cooling, vacuum tank, and fast anti-parallel ("clipper") diodes with grading capacitors. The TRIUMF group is using designs based on the KAON Factory. BNL will be responsible for controls and timing, as well as a new A10 building, and will provide new cable runs to A10 as short as possible to minimize any tail on the field pulse.

4.2 Modifications for MECO

Prior to the BNL/AGS-RSVP project, modifications of the Booster and AGS for MECO appeared in the MECO WBS. These items have been moved into the Booster AGS . There are two components to the MECO modifications. First a vertical AC dipole which can operate in CW mode and provide enough kick to displace the entire beam in the accelerator outside of the vacuum chamber. Second is a set of stripe-line kickers and associated electronics and power amplifiers that are capable of negating the kick of the AC-dipole for the high intensity bunches. The purpose of these two systems working together is to ensure a high degree of intra-bunch extinction. These two systems are critical for the successful operation of the MECO experiment.
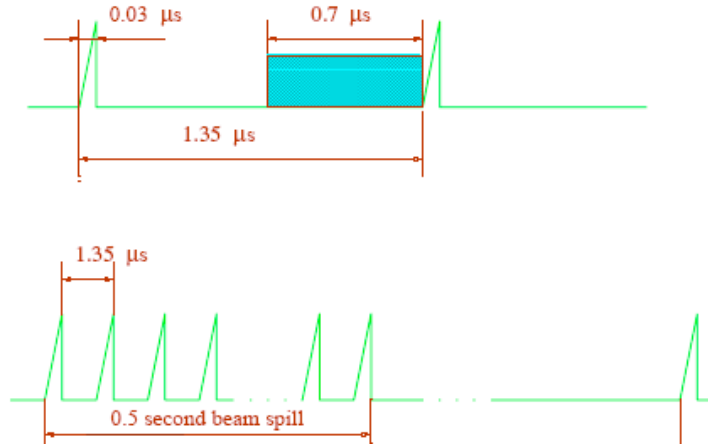

Figure 8. A schematic picture of the MECO beam time structure. The top drawing shows the micro-structure, with 30 ns proton pulses separated by 1.35 μs. The shaded region is the time during which conversion electrons are detected. The botton drawing shows the macro-structure with a 0.5 s train of micro-pulses in a 1.0 s accelerator cycle.

As discussed in the MECO TDR, a pulsed beam is crucial to reduce prompt backgrounds to an acceptable level. The required muon beam pulse duration $\tau \ll \tau_\mu$ is separated by approximately $\tau_\mu = 880$ ns, the mean lifetime of the muon Coulomb ground state in Al. A natural way to do this with the AGS is to fill two RF buckets separated by half the circumference of the machine, 1.35 μs, and then extract the beam while still bunched. Figure 8 shows schematically the time structure of the proposed beam.

Two machine operating parameters are affected by the pulsed beam requirement. First is the amount of beam extracted between the filled bunches. This is characterized by the extinction, defined as the ratio of the proton flux in a time interval between the two bunches to that in a filled bucket. Second is the intensity in the filled buckets required to reach the MECO muon intensity goal. We believe that acceptable values of the first parameter can be achieved, based on beam experiments that have been done to test this method of extraction and measurements of the extinction. The AGS has operated with 6, 8 and 12 buckets in the 2.7 μs revolution time. Minimizing the number of unfilled RF buckets is an advantage, since only particles in RF buckets can remain in stable orbits during acceleration. We propose that the AGS would run with harmonic number 6 (6 RF buckets in the revolution time) with a goal of achieving 2.10^{13} protons per cycle (1.10^{13} protons per filled RF bucket), the maximum intensity that has been demonstrated in previous AGS high intensity running. The maximum throughput that has been demonstrated is $2.2.10^{13}$ protons/sec in the AGS. C-AD accelerator physicists believe that doubling the density is possible. This is due to two differences in MECO vs. standard running conditions. First, only two transfers from the booster to the AGS will be required. Hence, beam will be stored at transfer energy, where space charge effects are most severe, for only 160 ms. Secondly, the beam will not be accelerated through transition. Beam instabilities at transition restrict the bucket density during normal operations and this limitation will not exist. No tests have yet been done of operation at the elevated bucket intensity. Since only two transfers from the booster are required and we only accelerate to 7.5 GeV, the cycle time is short. The main limitation on achieving the desired intensity will be losses during the cycle. Tests have yet to be done of an operation at the desired beam throughput. The absolute cycle time for MECO will be limited by the magnitude of the losses.

There may be advantages to producing a pulsed beam with spacing 2.7 μs. This could be achieved by running the AGS at higher harmonic number (12, for example) and filling two adjacent buckets. The two filled buckets would then be coalesced just before extraction, resulting in a single bunch in the 2.7 μs revolution time. This running mode is particularly advantageous if a calorimeter with long collection time, e.g., BGO crystals, is used. It would allow a longer detection time (up to 1.8 μs out of 2.7 μs), resulting in a gain in sensitivity per unit running time. The disadvantage is the higher instantaneous intensity, since all the beam is now in one bunch rather than two. The CA-D accelerator physicists believe that either mode of operation is viable. The choice of the operating mode would not have to be made until rather late and could be changed during the experiment.

Some extinction tests have been done. One RF bucket was filled and accelerated to 24 GeV and the bunched beam was slow extracted. We measured the trigger rate in a neutral kaon decay experiment at various times with respect to the RF bucket. That trigger is known to have unmeasurably small rate when high energy protons are not hitting the Kaon production target. Thus the rate is proportional to the rate of protons hitting the target. Figure 9 shows the relative intensity as a function of time with respect to the filled bucket. The extinction between buckets is below 10^{-6} and in unfilled buckets is of order 10^{-3}. The solid histogram and dots are result from measurements with a QVT and scalars respectively. Both were used in order to get a good measure of the main pulse shape and a good dynamic range. The extracted pulse has a width of about 30 ns. During these tests, no beam time was available to understand the source of beam in unfilled buckets nor was any tuning done to reduce beam in unfilled buckets.
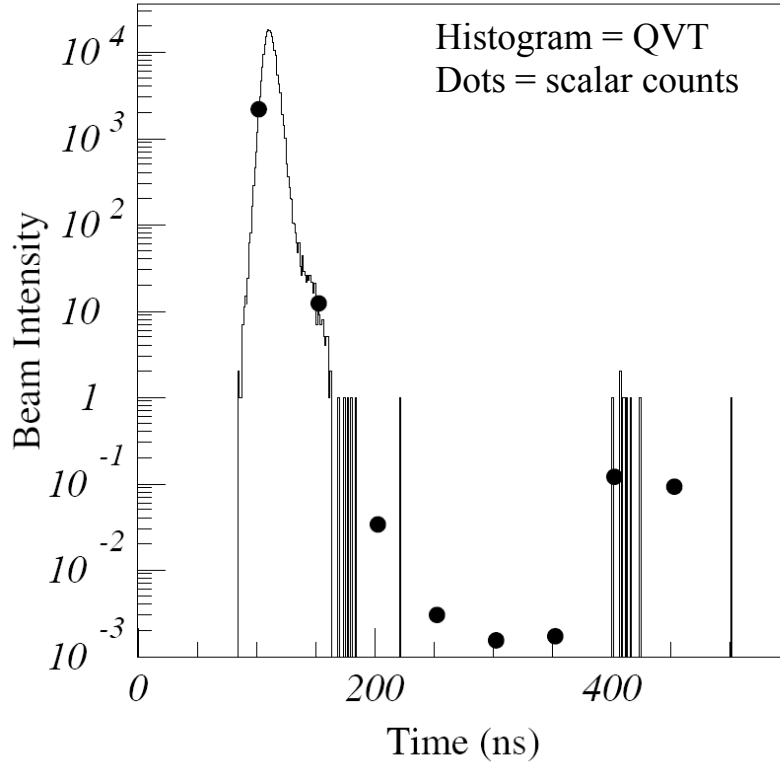
Figure 9. Plot of the beam intensity as a function of time with respect to pulses in the bunched beam extracted from the AGS.

A second study was carried out using the E787 detector. That experiment used 24 GeV proton beam incident on a platinum target to produce a secondary beam of 720 MeV/c K+. The beam is defined by a series of counters including a Cerenkov counter and Pb glass detector. For the test, the proton beam was extracted at 7.4 GeV/c and the secondary beam tuned to 200 MeV/c. Pions of momentum 200 MeV/c have approximately the same beta as 720 MeV/c kaons and will trigger the Cerenkov counter. The pion rate was measured by a coincidence between an upstream scintillation counter and the Cerenkov counter. One AGS RF bucket was filled, producing bunches separated by 2.7 μs. Approximately 105 pions per 0.3s spill were counted. The measurement consisted of determining the total pion rate and comparing it to the rate between bunches. The total rate used a coincidence with a signal 900 ns long centered on the extracted RF bucket. The background was measured in a 1800 ns interval between the filled bunches. The extinction (defined as the ratio of these count rates, corrected by about a factor 2 for saturation) was measured to be ~1.0 x10^{-7}. Again, the test time did not allow signifcant tuning to improve the spill quality.

These tests are quite promising. The desired extinction goal of better than 10^{-9} from the AGS is within reach. Two possibilities have been explored. The first involves a system of kickers in the AGS ring. This method of improving the extinction has the advantage that the kickers will run continuously during acceleration and require relatively small field since the beam is kicked many times. The basic idea of the system is to use two magnet systems in the AGS ring. One magnet

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produces a field modulated at 60 kHz. This would serve to destabilize the beam, and only low field is required for this purpose. To preserve the stability of the beam in the filled RF buckets, a kicker is operated at the frequency of the filled RF buckets, about 740 kHz in the case of two filled buckets in the 2.7 μs revolution time of the machine. The field integral in this kicker is adjusted to be equal and opposite in magnitude to that of the sinusoidally modulated magnet, and it fires only when the filled buckets pass through it. Hence, the net momentum transfer to protons in the filled RF buckets is zero. The second system consists of an external kicker, and is described in the MECO TDR. An additional piece of the AGS gap cleaning system is to include a set of collimators in the external beam line. The dynamics of the internal gap cleaning process are such that particles that do get extracted during the intra-bunch period will have large amplitudes. Careful placement of a set of collimators in the external beam line will capture the large-amplitude out of time particles.

The Booster/AGS WBS includes a gap cleaning system for MECO consisting of an AC-dipole that will modulate at 60 kHz to destabilize the beam. The second part of the gap cleaning system consists of 4 sets of strip-line kicker, operating at 740 kHz, and will act together to counteract the effect of the AC-dipole on the main bunches. In addition, modifications for the ASG RF system are included to allow the three systems, the AC-dipole, the strip-line kickers, and the main RF system to work synchronously on the beam. The addition of collimators to the external beam lines is in the Switchyard and MECO beam line WBS.

One additional modification for MECO is a system to increase the cooling capacity of the AGS RF power amplifier tubes. The current RF system is only capable of operating at a maximum duty factor of 50 %. To achieve the high throughput beam intensities for MECO may require operating the AGS RF system at as high as an 80 % duty factor.

4.3 Modifications for KOPIO

There are three components to the KOPIO modifications two of which are co-funded by TRIUMF. These are an upgrade to the AGS injection kicker subsystems, a new 25 MHz RF cavity, and a new 100 MHz RF cavity. The upgrade to the injection kickers will permit higher injection momentum and permit for higher beam intensities for KOPIO. The new 25 MHz RF cavity is used to generate the micro-bunch structure in the slow extracted beam to KOPIO. The 100 MHz RF cavity allows making even shorter bunches in the micro-bunch structure. These three systems are critical for achieving the KOPIO bunch and beam intensity goals.

The KOPIO Experiment requires that the AGS produce high intensity extracted proton beams with a time structure characterized by very short pulses called microbunches cleanly separated from each other by an interval of 40 ns. The microbunches are needed so that a measurement of the kaon velocity can be made via time-of-flight. The flight time is determined from the moment the primary proton beam strikes the KOPIO target and the measured time when a photon from π^0 decay is observed in the Preradiator and Calorimeter. The time spread of the proton microbunch interacting in the target should not dominate the timing resolution. Contributions to the timing resolution come from the Preradiator and Calorimeter which have measured time resolutions on the order of $(90{\sim}ps)/\sqrt{E}$ for photons of energy E in GeV. Additional contributions to the time resolution come from the uncertainty in the location of the production point in the target which

adds on the order of 100~ps to the time resolution as a function of the kaon momentum. Based on simulation studies of time resolution on the kaon velocity, the optimal microbunch width was selected to be 200~ps RMS.

The microbunching technique proposed for KOPIO is compatible with slow extraction schemes such as that used at the AGS. It proceeds according to the following steps. First protons are injected into the AGS in 6 buckets, and accelerated to the operating momentum of 25.5 GeV/c by using the main AGS RF accelerating cavities. Then the RF voltage is shut off causing the protons in the 6 buckets to debunch, spreading the protons around the AGS in a continuous band. This debunching establishes the DC coasting beam that will be extracted, uniform in phase, with a fractional momentum distribution defined by the longitudinal emittance. Typically, an additional RF gymnastic is done, in which the phase of the RF is caused to jump to the unstable fixed point for a few milliseconds just before shutting the RF off. When properly executed with a low RF voltage, this increases the momentum spread slightly, but, more importantly, shapes the radial distribution of the debunched beam.

A beam dynamics simulation called SLEX-Long1D has been used to evaluate this microbunch extraction process. It makes use of coordinates relative to a reference frame co-rotating with the equilibrium orbit. The simulation does not make use of beam transport elements, but instead calculates an orbit-by-orbit transfer function based on a symplectic Hamiltonian. The beam dynamics for the ith particle depends on the vertical and horizontal coordinates, x_i, x_i', y_i, and y_i' as well as the orbital coordinates s_i and s_i' where the ``prime'' denotes the derivative with respect to the equilibrium orbit parameter s. This $2 + 2$ dimensional simulation tracks horizontal (transverse) and longitudinal motion only, with no vertical component. There is no explicit coupling in the Hamiltonian between the transverse and longitudinal motion; only that provided by chromatic dependence of the beam tune. Once the coasting beam is established, the extraction RF cavities are brought on at a frequency that is far from any betatron resonance. KOPIO plans to make use of a 25-MHz cavity and a 100-MHz harmonic cavity. The voltage on both cavities is increased slowly so that the beam response is adiabatic. Once the cavities are at operating voltage of 150 kV, the frequency is reduced to bring the beam closer and closer to the 8 2/3 resonance. Those beam particles that are far from resonance will receive RF kicks that sometimes increase their energy and sometimes decrease their energy, giving no net effect. Only a narrow momentum band of beam particles will be within the resonance condition. The RF potential gives them a net increase in energy each time they pass through the RF cavities. The resonance condition, created by a set of sextupoles in the AGS, causes progressively larger transverse oscillations producing a large-amplitude horizontal deviation from the equilibrium orbit. This horizontal excursion takes the particle across the aperture of the extraction septum that bends the particle trajectory out of the circulating beam orbit, and towards the extraction beam line.

The narrowness of the regions in phase space that overlap the extraction resonance determines the shortness of the extracted microbunches in the time domain. The overlap region can be made narrower by increasing the depth of the RF buckets by increasing the voltage on the RF cavities. But the microbunch width depends only on the square root of the cavity voltage, making large gains are hard to achieve in this manner. Adding a 100-MHz harmonic cavity to the 25-MHz cavity allows for tighter time structure without the difficulty of operating the cavities at prohibitively high voltages. The effect of the higher harmonic cavity is to steepen up the phase

dependence of the RF buckets, much like trying to create a square wave by adding higher harmonics to a sine wave.

Since only the particles at the nodes of the RF buckets receive transverse displacements, there is no mechanism for extracting particles at times between the microbunches. This extraction technique offers very tight time distributions with no contribution from particles extracted between the microbunches.

Studies with test beams were conducted in 2002 and 2004 to measure the microbunch width and interbunch extinction performance of the AGS using this extraction technique. In 2002 a simple photon telescope observing a thin target in the extracted proton beam looked for the prompt photons to reproduce the microbunch time structure of the proton beam. By using a single 93-MHz RF cavity operating at 22~kV, a microbunch width of 240~ps was observed. This result is in good agreement with the expected microbunch width and the simulation result of 218~ps. Figure 10 shows the data and simulation results for the test-beam case.
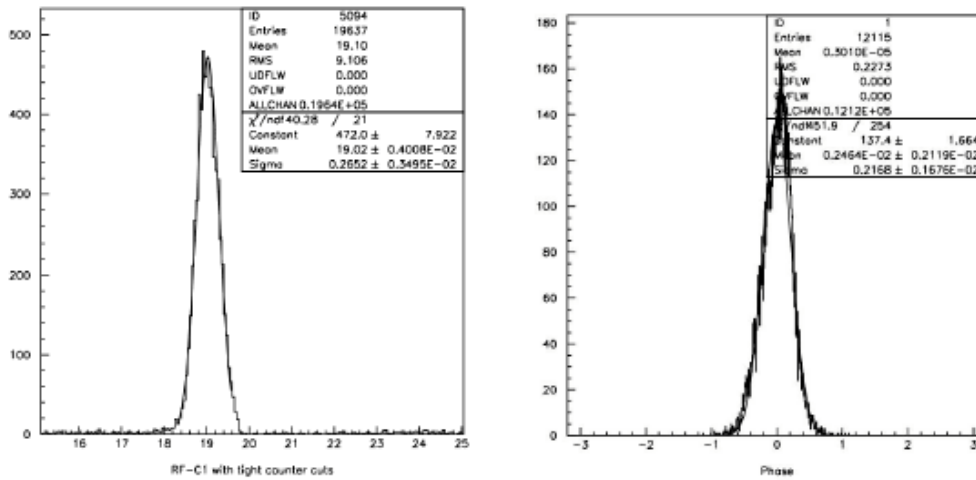

Figure 10. Measured and simulated microbunch time distributions for a 93-MHz RF cavity operating at 22 kV.

The Booster/AGS WBS includes both the 25 MHz RF system and the 100 MHz RF system. The 25 MHz system is being built in collaboration with TRIUMF. BNL is responsible for the power amplifier design, the interface to the RF cavity, and the installation of the cavity. The 100 MHz RF system is being designed and built entirely by BNL.

5. The AGS Switchyard

The existing AGS Switchyard was designed and built over 25 years ago. Its purpose was to service many experiments simultaneously. Since the AGS was capable of providing more beam per cycle than any single experiment was capable of accepting, it was a very cost effective method of operation. The existing switchyard was designed at a time when the peak AGS intensity was below 10^{13} protons per cycle and beam was injected into the AGS directly from the LINAC. Nevertheless it has operated very well in the post-Booster era and beam intensities in excess of 7×10^{13} have been delivered. The key feature of operation of the Switchyard is the splitting of beams. The operation of RSVP does not require split beams. The acceptance of the beam splitters is not sufficient to allow an un-split beam transport, without beam losses on the beam splitters. This is especially true for MECO, which operates at lower energy, and thus with a

larger beam. A new Switchyard is being proposed, in which all beam splits are removed. MECO will be situated in the A-line (7.5 GeV/c beam) and K0PI0 will be situated in the B-line (25.5 GeV/c beam).

The possibility of running E949 (C-line) during RSVP construction will be accommodated but will require a new beam dump (this is part of the E949 budget request) and completion of the switchyard work to the point where work outside the switchyard can proceed while E949 runs. The AGS NASA Radiobiology experiment (A3 beam) will be relocated. The RHIC e-cooling R&D project will be situated in the North East Building Addition (C1/C5 beam area) and the D-line will be decommissioned. No other Slow Beam experiments (including test beams) will be accommodated at this time. Beam will be delivered to only one experiment at a time (no beam splits).

5.1 Planned changes to the AGS switchyard

The present switchyard design incorporates 3 electrostatic beam splitters with motion controls, three thin Lambertson magnets with motion controls, several thick Lambertson magnets, skew quads, tilted dipoles, lots of beam instrumentation, ramped dipoles, beam servo dipoles etc. All this allows the AGS beam to be split into up to 4 beam lines, something not needed by the RSVP experiments (MECO or K0PI0 run as an "OR"). We propose to simplify the switchyard to allow only one beam line at a time. Simple dipole magnet switches will be used to select the appropriate beam line. All splitters, Lambertsons, servos, ramps, skew quads etc will be removed as well as the vertical pitching presently needed to thread the beams through Lambertson apertures. This will make available shielding, transport magnets and additional floor space for the RSVP experiments and should help offset the costs.

A new switchyard preliminary design along with the required beam line elements, shielding, vacuum, services, instrumentation, and controls have been completed. New drawings and documentation to complete the WBS costs were produced.

The beam optics design for RSVP primary proton transports presents near zero dispersion (position and angle) beams to the respective target stations, thereby avoiding the need for servo-SWICS and ramped dipoles to keep the beams on target. These are described in the respective MECO and KOPIO chapters.

The plan is to install a beam plug downstream of the 4 quads (CQ1-4) that bring the beam into the switchyard and configure the shielding so that work in the switchyard can be done while RHIC operates with either HI or protons. Only minimal beam instrumentation is required in this simplified switchyard. These changes to the switchyard will result in a more robust switchyard, minimal activation of components, easier beam tuning and lower maintenance cost.

This work has no impact on RHIC operations. It does significantly impact RSVP construction and operations, since included in the design are provisions for RSVP construction and maintenance during RHIC and RSVP operations, which are constrained and limited by the current switchyard configuration. The layout of the new switchyard including the beam lines, shielding and the MECO and KOPIO experiment locations are shown in figure 11.
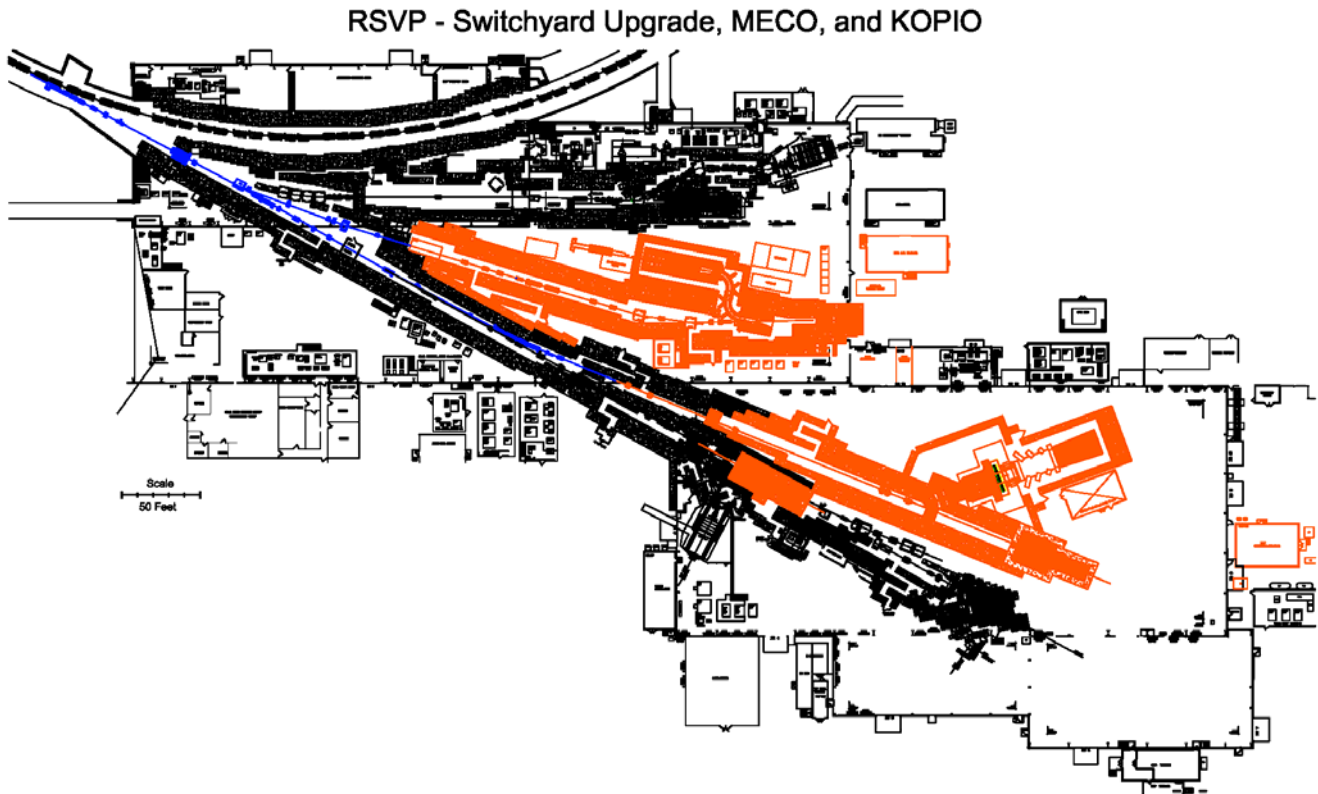
Figure 11. The switchyard and experimental beam lines. The primary beam lines are in blue, and the secondary beam lines for MECO and KOPIO respectively are in red.

5.2 AGS NASA Facility

In the event NASA wishes to continue biology experiments using the AGS, the facility presently located in the A3 beam line can be moved (including the trailer) to the switchyard near the Switchyard East Gate.

5.3 Switchyard shielding

Shielding modifications are kept to a minimum, since the existing shielding is basically in the correct configuration. The major changes are in the shielding between the AGS and the switchyard, which will be modified to allow access to the switchyard and beam line areas during RHIC or polarized proton operations. The shielding interfaces to the A line (for MECO) and B line (for KOPIO) will be modified to accommodate the new design and to allow access to those areas when one or the other is in operation.

5.4 Switchyard infrastructure

The new switchyard design does not require as many vacuum interfaces, allowing for improved vacuum without significant upgrade of the vacuum system infrastructure. Many flanges could be

welded, eliminating many vacuum failure points. The vacuum around the MECO RF modulated magnet needs to be better than the rest of the switchyard. The interfaces for this section will be thin windows.

The power requirements for the new switchyard are reduced, since the number of elements is reduced. The number of power supplies is reduced. Power distributions will need to be adjusted, since the load distribution is changed, but this is a minimal alteration.

All moveable magnets are eliminated. Most magnets are recycled elements, so no new designs are required, with the possible exception of the BD4 replacement. This thick Lambertson magnet is required to permit beam to pass through to C target or be bent into B line to KOPIO. Collimators to be included are a first stage collimator in the upstream switchyard, and secondary collimators in the beam lines. The main purpose of the collimators is to remove large amplitude particles and beam halo.

Existing buildings and services will support the new systems. New controls and instrumentation electronics will be located in an air conditioned trailer inside the main experimental area building.

5.5 Instrumentation

The switchyard has historically been instrumented with flags, since this is the best method of observing the split beams (on a phosphor screen). But without split beams flags, which require video and more complex data acquisition systems, are no longer required. There is also a large set of existing beam loss monitors, which can be reduced to less than half the existing set. Some repair and upgrade of this system is required, to be in proper condition for long term RSVP operation, but for the most part does not require significant redesign or modification. New profile monitors, either segmented wire ion chambers (SWIC), or external profile monitors (EPM). In most of the Switchyard EPM's will be utilized, since they do not require any movable parts. This permits non-destructive beam measurements and simplifies the mechanical operation. In the upstream part of the Switchyard we will use one SWIC, since this area is part of the AGS vacuum and EPM's will not work when the vacuum is better than 0.1 torr.

5.6 Controls
The following controls items must be addressed to ensure maintainable delivery of high intensity protons. This is detailed in a later chapter.
1) Standard VME interfaces will be provided for the instrumentation systems for which legacy controls interfaces are un-maintainable.

2) Software and database engineering will be needed for both new front-end interfaces and console level applications.

5.7 Personnel Access Controls

The access control safety system (PASS) for the switchyard and the beam lines will use networked Programmable Logic Controllers [PLC]. In order to provide the required dual independent protection the area served by PASS has two independent PLC's [field machines]. These field machines are separately networked [DH+] into 2 divisions [A and B]. Each division

independently provides full protection. All the I/O's (gate switches, critical devices, etc.) are redundantly monitored by both PLC systems. The MCR operator interface utilizes touch screen displays [flat panels] on a command network that is connected through firewall machines to the separate divisions.

6. REFERENCES

C-AD AGS RSVP Project Office web site:
http://server.cad.bnl.gov/esfd/RSVP/RSVP_AGS_WBS.htm

BNL SBMS Subject Area: Accelerator Safety, Design Practice for Known Beam-Loss Locations, Effective Date: September 2000 (https://sbms.bnl.gov/standard/1r/1r09e011.htm)

Chapter III. The MECO experiment

1. Overview: Experimental Support and Facility (ES&F) for MECO

The layout of the MECO experiment is shown in Figure 1. It will be constructed at the end of the A-line in the AGS East Experimental Area (EEA) in building (Bldg. 912). MECO seeks to observe evidence of the muon to electron conversion, a process forbidden by the Standard Model, with a sensitivity 10,000 times better than previously achieved. MECO will use an extremely intense muon beam from pion decays produced from an intense bunched proton beam impinging on the experiment target. The required time structure will be achieved by exploiting the time structure in the circulating AGS beam that is defined by the accelerating RF structure.
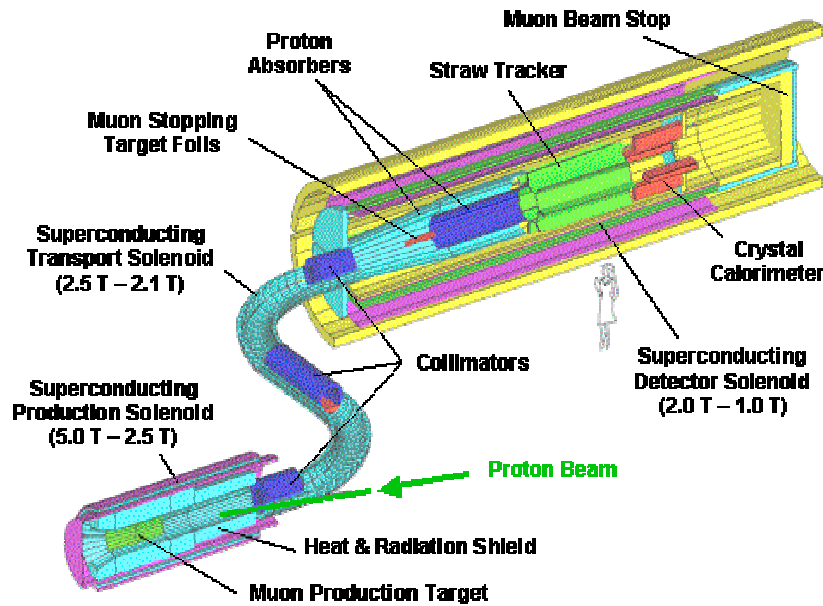

Figure 1: A cutaway of the layout of the MECO experiment

The C-AD ES&F Division is responsible for the design and construction of the new primary proton beam line. They also provide operation support and maintenance of the production target, the installation of experimental equipment and related facilities, technical support for the operation of the three large SC solenoid magnets, and technical support for the experimental activities during physics running.

2. Beam Transport Design to the Target. A new beam line: A-Line

MECO will make use of a mini-bunched extracted proton beam, in which bunches are spaced at 1.35 μs, with the momentum of 7.5 GeV/c, the intensity of 20.10^{12} proton per macro-pulse, and a repetition rate of 1.0 second (50 % duty factor).

The entire A-line must be raised by 0.37m to match the MECO target height, which is 2.35m from the experimental building floor, or 0.37m above the plane of the AGS ring. The height of

the MECO beam is constrained by the massive cosmic ray shielding. This elevation is achieved by bending the beam at the upstream end of the switchyard using two pitching magnets (AP3-4).

The new beam optics design and transport has been completed, Figure 2 The MECO experiment requires specific extinction between bunches of the order of one part in 10^9. This goal is achieved by developing and installing a radio frequency modulated magnet (RFMM) in the A-line. This in addition to AGS modifications (AC dipole and strip-line kickers) which internally clean up the protons between the filled buckets (see related section). This magnet will run synchronously with the AGS internal RF at 0.74 MHz and generates sinusoidal magnetic field, which kicks the unwanted inter-bunch protons vertically in one direction, while channeling the beam bunches in the opposite direction. Two Lambertson septum magnets located at 20m downstream of RFMM will further separate the two beams. The desired protons in the mini-bunches will pass through the field-free region of Lambertson magnets and travel towards the target. The inter-bunch protons will be further bent (by the Lambertson magnets) into a detector system so that the actual extinction will be identified and monitored quantitatively. Another possibility for extinction monitoring is to use a spectral magnet and a high frequency detector system to measure the transmitted proton beam time structure behind the experiment target (near the beam stop). If adopted, collimators will replace the Lambertson magnets.

The A-line optics design has the following constraints: the beam envelop is well within the magnet apertures to minimize losses, a parallel beam of less than 30 mm within the RFMM and Lambertson magnets region, compensate for the vertical and horizontal dispersions and focus the beam spot at the target. The required beam spot on target is such that 95% of the beam should be within an 8mm diameter.
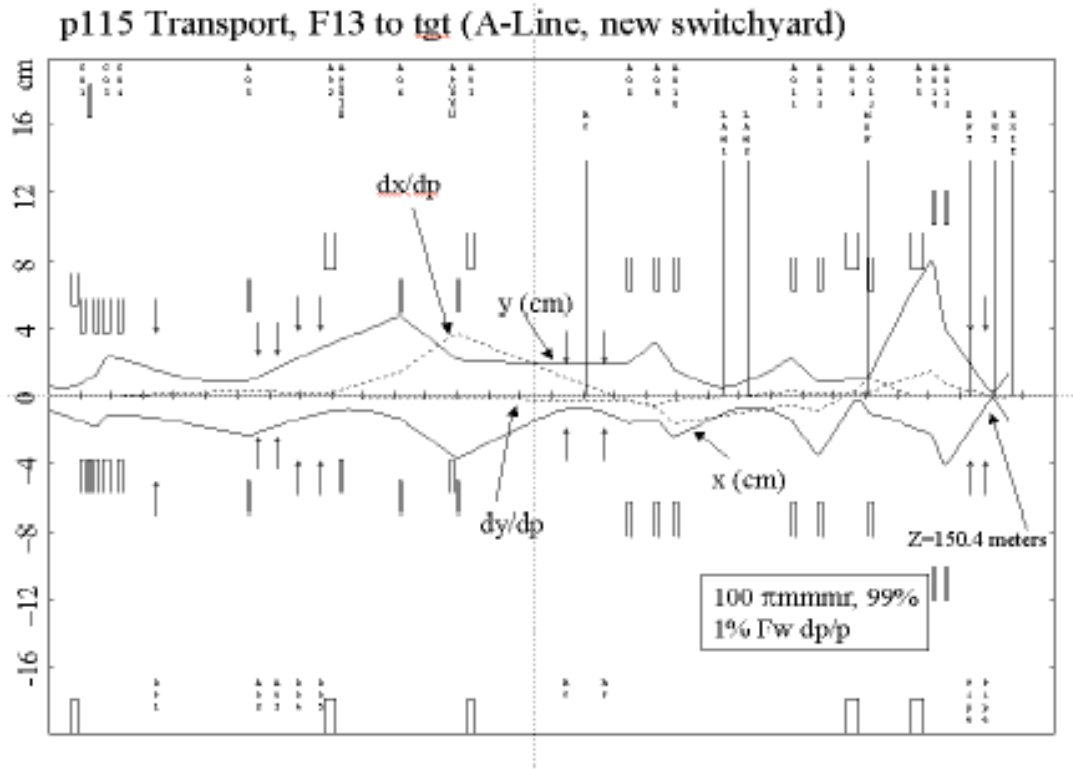

Figure 2. The A-line optics design.

The beam design assumes a 7.5 GeV/c primary beam with emittance of 100 πmm.mr and a 1% Δp/p momentum bite. Quadrupole magnets are positioned between the RFMM and Labmertson magnets to symmetrically match the parallel beam profiles. The design reserves enough drift space between Lambertson magnets and the target station to ensure that there is sufficient spatial beam separation for the apparatus used in the extinction measurement. The final focusing quadrupole (AQ14-15) and pitching magnets also must be located at a distance, to provide space for shielding around the solenoid magnets. These constraints have pushed the proton beam dump to the end of the building. The last dipole (AD5) creates a 9° bend, which serves as the beam switch, final horizontal steering, and momentum selection. The last two pitching magnets (AP5-6) ensure the beam hits the target in a helical path through the gradient axial magnetic field.

The new beam line utilizes existing or modified magnetic elements from our inventory to the extent possible. The two pitching magnets (AP5-6) and the two Lambertson septum magnets must be designed and fabricated specially for this application.

A large potion of the existing infrastructure (shielding blocks, labyrinths, beam components, power supplies, cables, and beam dumps) must be removed from the former A-primary, A1, A2, and A3 lines to make room for the new beam line. The entire D6 line must be eliminated to make room for the positioning of the MECO experiment. Much of the existing materiel will be handled as radioactive waste, which includes vacuum elements, old target stations and shielding materials in their proximity.

In order to reduce the beam loss during the high intensity proton transport, the vacuum inside the beam pipe should be maintained below 10^{-3} torr. The vacuum in the RFMM region is at 5.10^{-6} torr.

The beam line will be equipped with appropriate instrumentation to assist in tuning and to ensure a clean transport (details are provided in the instrumentation chapter)

1. External Beam Profile Monitors (EPM): Four (4) EPM's in MECO A-line, to monitor the horizontal/vertical beam profile and position.

2. Current Transformers (CT): Two (2) current transformers located at downstream of the RFMM and upstream of the production solenoid (downstream of AD5), to monitor the beam intensity, before and after the extinction device RFMM.

3. Beam Loss Monitor (BLM): The A-line will be equipped with a number of the beam loss monitors (line type and point type), in order to detect the losses resulted from an individual or a group of beam elements. These will also help in optimizing the beam transport efficiency and minimize activation to the equipment. Detailed loss monitor distributions will be determined, after the beam line and shielding designs are finalized and reviewed by the Radiation Safety Committee.

4. Beam line personnel safety systems and related interlocks (details elsewhere).

3. The MECO production target

The MECO collaboration is responsible for the conceptual design of the production target shown in Figure 3. The BNL engineers will verify the design and calculations fabricate the target and install it inside the production solenoid (PS). The target is made of gold or platinum, 160 mm in length and 6 mm in diameter, cooled by a closed circulating water system. The beam energy deposition in the target is estimated as 5 kW on average and 10 kW peak. The expected target temperatures are shown in figure 4. The conceptual design calls for handling the target assembly as a single unit for purposes of replacement, storage, and any other services. This shall be performed remotely to minimize the radiation exposure to personnel [1].
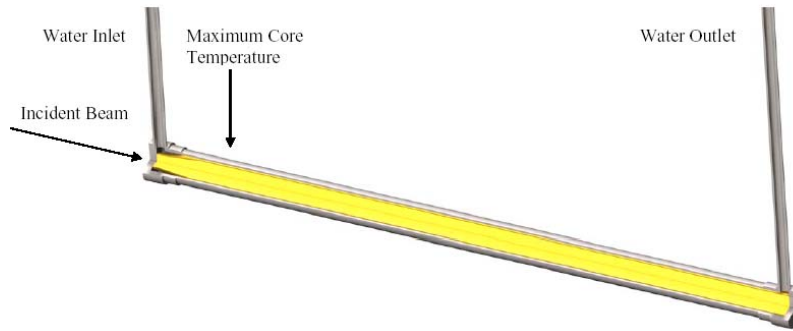

Figure 3. The MECO water-cooled production target cutaway view
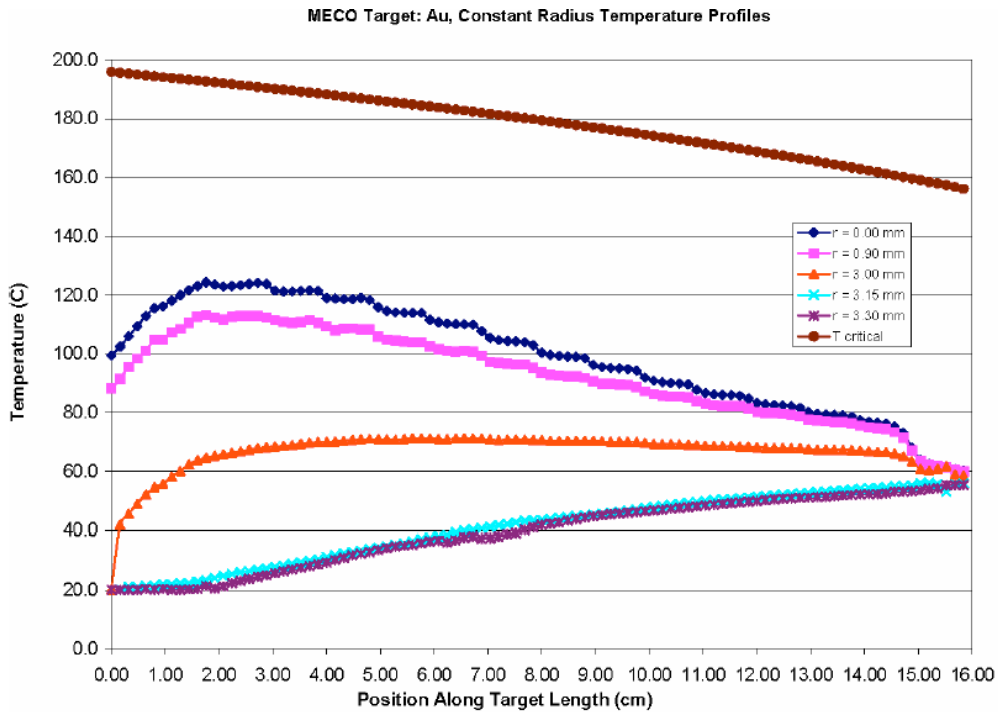

Figure 4. The steady state target temperature at fixed radii vs position along the target

The high intensity proton beam must hit the target through an 80mm diameter pipe, which is mounted in the gap between the PS and TS (transport solenoid) cryostats. A window at the end

of this pipe separates the beam line vacuum (10^{-3} torr) from PS vacuum (10^{-4} torr). Accurate targeting is crucial for pion production, SC magnet quench prevention, and radiation reduction in the building. The following instrumentation is considered essential to ensure proper targeting:

1. 1 picture frame type beam loss monitor installed at the beam entrance to the PS;
2. 10 sets of PIN photodiode type loss monitors mounted symmetrically on the outer surface of the PS radiation heat shield (i.e., the inner surface of the PS cryostat);
3. 2 flags and 1 camera installed to mirror the beam spot from the down stream end of the target;
4. A number of temperature sensors mounted around the radiation heat shield.

In addition, two sets of collimators in the beam line are used to restrict deviations. Passive heavy metal shielding on the TS cryostat outer surface is also being considered by the collaboration [2].

4.0 Beam line and experimental area construction

4.1 Beam line construction

Based on the optics design described in section 1.0, beam elements were selected existing stock and installed accordingly. Table 1 lists the parameters and status of these devices.

Table 1. Magnet Parameter List for MECO A-line

Magnet Name	Magnet Type	L_eff (inch)	Field/Grad (kG/kG/in)	Integral (kG in/kG)	Io (kA)	R (m-Ohm)	Voltage (V)	Power (kW)	PS Status
AQ8	5Q36	38.5	0.9662	37.1989	0.24	97.5	23.0	5.4	Exists
AQ9	5Q36	38.5	-1.8275	-70.3593	0.44	97.5	43.4	19.3	Exists
AQ10	5Q36	38.5	1.5055	57.9620	0.37	97.5	35.7	13.1	Exists
AQ11	5Q36	38.5	-1.5886	-61.1597	0.39	97.5	37.7	14.6	Exists
AQ12	5Q36	38.5	2.0850	80.2726	0.51	97.5	49.5	25.1	Exists
AD4	18D72	78.0	19.8207	1546.0170	2.24	45.8	102.7	230.1	Exists
AQ13	5Q36	38.5	3.1958	123.0395	0.78	97.5	75.9	59.0	Exists
AD5	18D72	78.0	19.8207	1546.0170	2.24	45.8	102.7	230.1	Exists
AQ14	8Q24	28.0	-3.1396	-87.9084	2.58	21.6	55.6	143.3	Exists
AQ15	8Q24	28.0	3.4001	95.2023	2.87	21.6	62.0	177.7	Exists
AP5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
AP6	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

The applied polarity convention used in the above table is: for dipole magnets, a positive sign stands for bending in the same direction as AGS beam, for quadupole magnets, a positive sign stands for horizontally focusing. The AP5-6 parameters are yet to be determined. The two Lambertson magnets are not listed. The plan calls for modifying existing switchyard Lambertson septa depending upon the final decision of extinction monitoring scheme.

It is planned to construct a temporary target station and beam dump for a MECO low intensity beam test, prior to completion of the SC magnet system to be used for beam tuning exercises.

4.2 The SC solenoid magnet system

C-A Department is responsible for the installations of the SC magnet system, including the return yokes, cryogenic system, and the power supplies. This is done under the guidance of the MECO magnet personnel. The C-A Department (with the help of the BNL Magnet Division) is responsible for the design and fabrication of cryogenic system, the magnet power supplies, and quench detection/protection systems. The technical designs of these systems are described in the MECO CDR, WBS 1.5 (MECO magnet system).

4.3 Shielding design and installation for the experimental area
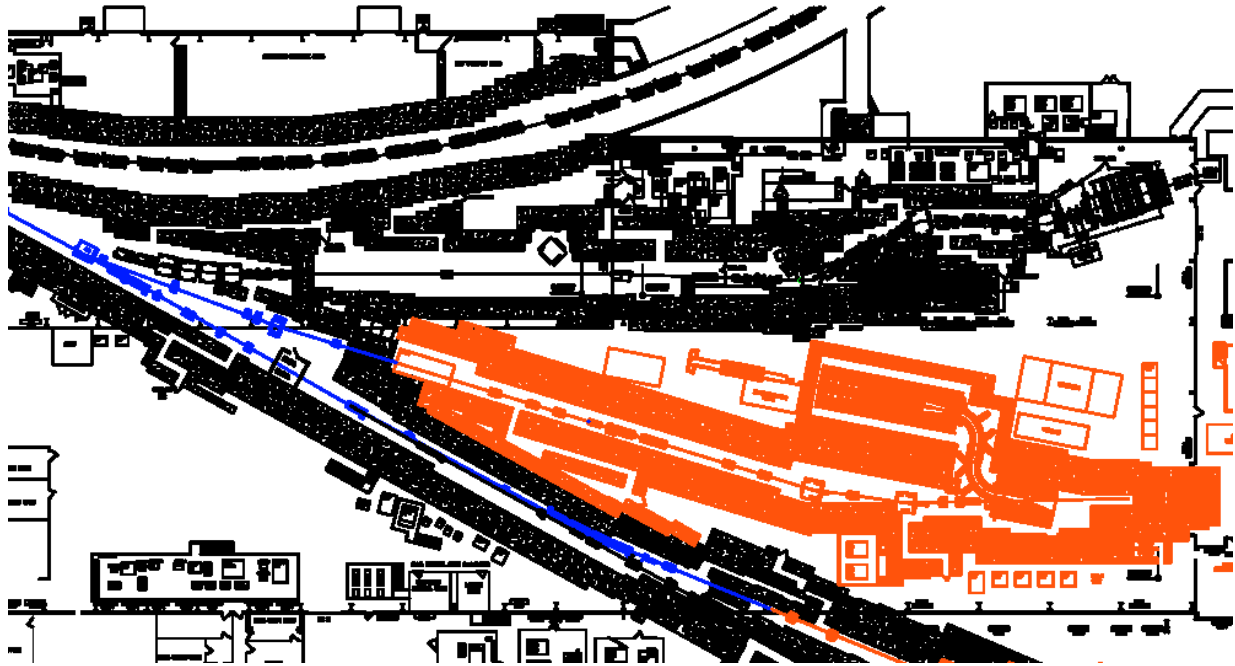

Figure 5. The layout of the MECO beam line and experiment shielding and beam dump (red).

The plan view of the present shielding and beam stop design are shown in figure 5. At this stage, the required shielding material and thickness were computed using an analytic formula [3]. The dose equivalent outside the lateral shielding was calculated by the exponential decay with the hadron mean free path through the materials. The present shielding design consists of 3.6 m heavy concrete (or equivalent) in addition to the PS assembly material. The dose equivalent behind the beam stop was calculated using an effective decay path for muon penetrations. The present beam stop consists a 4 m (width) by 7 m (depth) central part, which is surrounded by concrete blocks. The front face of the stop is 10 m away from the target. The present design is expected to reduce the dose outside the shielding (or behind the beam stop) to 25 mrem per man-year. The roof shielding is not shown in this layout. It is important to study the neutron scattering in the air (sky-shine effect) from the target region, and come up with a sufficient roof shield. It is

planned to complete the roof design, re-visit the side shielding and beam stop design, by using computer codes (MARS, MCNPX) in the near future.

The production target will be located inside of PS. Hybrid heavy metals (copper and tungsten) form a radiation heat shield surrounding the target area, to prevent PS magnet from quenching. The PS coils and cryostat walls also provide a certain degree of radiation shielding. The PS return yoke helps reduce the soil activation in the target area. A 0.75 meter thick steel sleeve is also included to further reduce the radiation exposure and to contain the magnetic fringe field in the experimental area.

The primary purpose of the return yoke outside DS (detector solenoid) is cosmic ray background shielding. This 0.5 meter thick steel sleeve will be surrounded by a 1-meter thick heavy concrete wall. The combined steel and concrete shielding also serve to protect the experimenters from high radiation.

There will be no return yokes outside the curved TS. Non-magnetic material (trimmed concrete blocks filled with boron-doped polyethylene) will be used for radiation shielding in this area, this to accommodate the interferences due to the V-shaped support rods for the TS coils.

4.4 Experimental Facilities

The former E964 counting house will be re-furbished to become the control room for the MECO experiment. A facility hut will be designed and built for the RFMM, located in the middle of A-line. An electronics hut will be built near the DS, for fast electronics signals.

5. Operations Support

During testing with beam, C-AD ES&F Division is responsible for the operations support. This includes:

  A. SC magnets operation support (cryogenic, vacuum, and electrical technicians support);
  B. Target operation;
  C. Proton beam line support (instrumentation, vacuum, and power supplies);
  D. Muon beam vacuum: muon beam volume is the entire internal region from TS to DS, which is designed by the MECO collaboration to E-4 torr;
  E. Liaison Engineer and liaison physicist support.

6.0 Environmental Protection and Personnel Safety Issues

The C-AD Experiment Safety Review Committee and the Radiation Safety Committee will review the hazards associated with the experiment at the design stage. Relevant corrective action and mitigation are then implemented.

Radiation hazard has been often discussed in previous sections. In the PS vicinity area, the floor will be modified and water proofed by an epoxy sealant coating, in order to reduce any soil contamination, in case a water leak occurs in this area (water is used for cooling the target and

heat radiation shield). A helium container will be installed in the space between the PS and the proton beam stop, in order to prevent and reduce the air borne radioactivity inside the shielded area. In A-line, interlocked beam loss monitors will be installed on all collimators. These are interlocked with the AGS extraction magnets, so that beam will be terminated immediately if the radiation level exceeds the set thresholds. The radiation dose at various locations will be checked and recorded on a daily basis by the Health Physics Group. The Liaison Physicist is tasked with periodic monitoring of the beam optics and magnet settings. The magnet settings read backs are also interlocked with the beam permit system.

The fringe field generated by SC solenoids is largely screened by the return yokes and steel shielding. Based upon the present floor design, the residual field at the experimental control room should be well below 5 Gauss.

Oxygen deficiency issues have to be addressed due to the presence of the large amount cryogens in the SC magnets. This is especially the case in the refrigerator room. People who work in the area will receive special training. Inside the shielded area, alarming oxygen deficiency detectors will be installed. ODH interlocked exhaust fans will also be installed in the MECO experimental area.

Building 912 is defined as Radiation area. Access to the shielded area (High Radiation Area) is prohibited when the beam is on. Three gates are designed to allow monitored personnel entry (with beam off and the respective devices locked out) in different modes (controlled access or restricted access) after the radiation survey is completed. Under the controlled access mode, An ID card must be scanned, and the single entry process is controlled and monitored by the C-A main control room. All gates are interlocked with beam permit condition via the C-A safety system.

7. References:

[1] **Production Target Reference Design** (MECO-Target-03-001), M. Hebert and J. Popp, 3 March 2004.

[2] **Energy Deposition in PS and TS Coils in Beam Normal and Fault Conditions** (MECO Internal Document, MECO-118), V. Tumakov and K. Brown, 9 December 2003.

[3] **A Guide to Radiation and Radioactivity Levels near High Energy Particle Accelerators**, A. H. Sullivan, Nuclear Technology Publishing, 1992
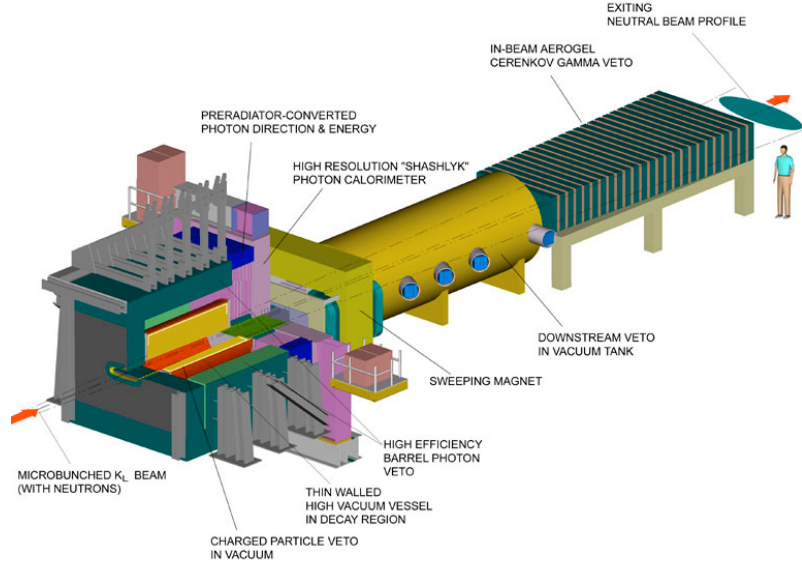
Chapter IV: The KOPIO beam line and experiment

Figure 1. The KOPIO experimental layout.

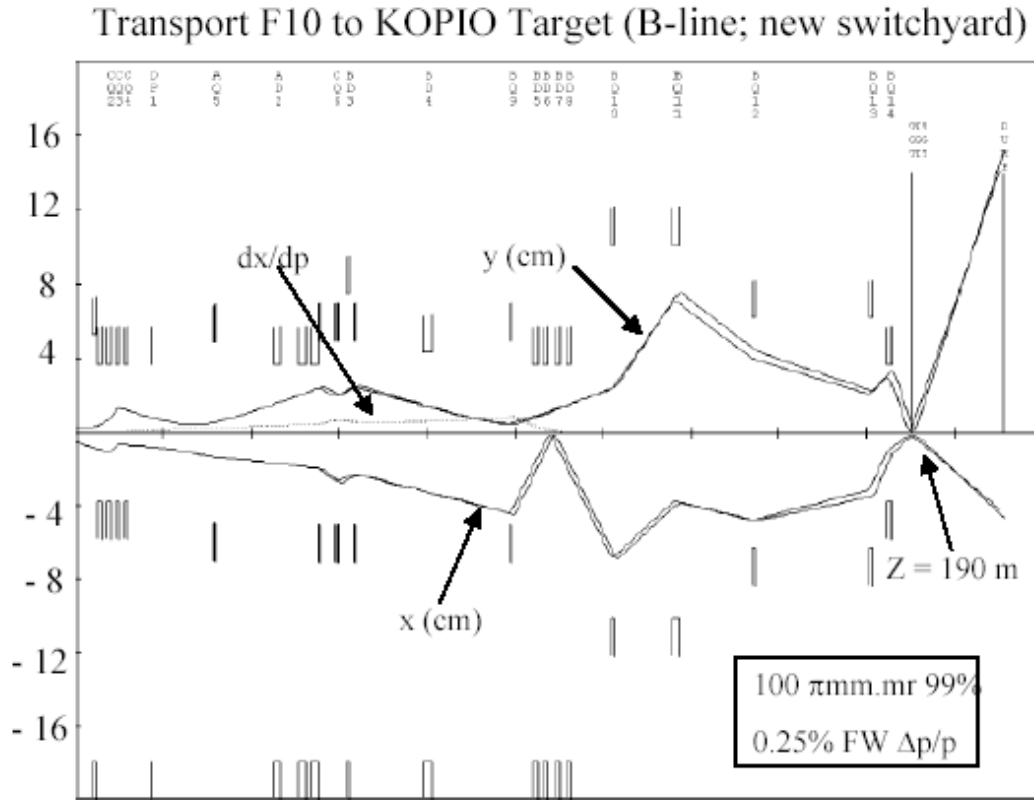## 1. Primary Beam Transport Modifications

Figure 2. The KOPIO beam line optics. The vertical axis is in cm.

KOPIO requires 100 TP of 25.5 GeV/c protons/spill, microbunched at 25 MHz with rms bunch widths of less than 260 ps. The optimum spill length will depend on available beam quality and intensity but is anticipated to be close to 4.9 seconds in duration with an AGS cycle time 2.3 longer. Because of the small vertical aperture of the secondary neutral beam collimators, the vertical spot size at the production target should be smaller than 2 mm with a similar constraint on the vertical alignment of the primary beam and target with the secondary beam collimators.

The redesign of the primary proton beam in the B Line minimizes momentum dispersion at the production target, thereby eliminating the need for programmed current ramps or feedback on beam transport dipole magnets to stabilize the horizontal position of the beam on the target by tracking the momentum variation of the beam during resonant extraction. Figure 2 shows the vertical and horizontal primary beam envelopes. The horizontal trace crosses the horizontal axis in the vicinity of BD6. The dispersion of an originally on-axis but -2.5%, off-momentum trajectory (dotted line) is seen to vanish near this location. Chromatic aberration of the off-momentum envelope is apparent the figure. The horizontal and vertical beam profiles of the proton beam at the center of the production target are displayed in Figure 3.
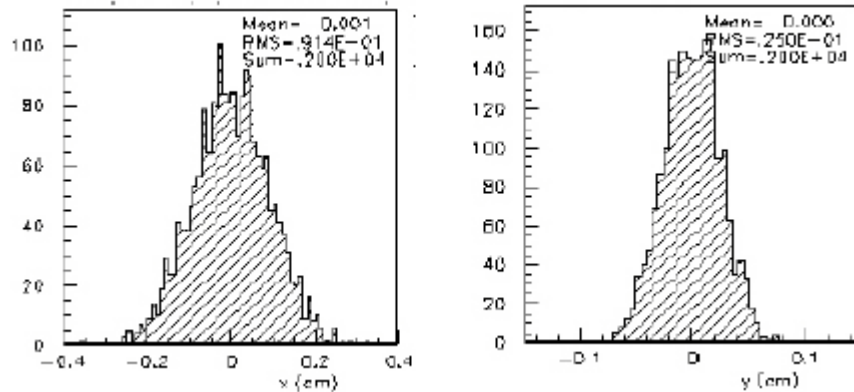

Figure 3. The horizontal and vertical beam spots at the KOPIO target

The primary beam magnets and power supplies are standard AGS equipment and are in stock. They are listed along with power requirements in Table 1 and Table 2 for the portion of the B Primary Beam transported from the dipole magnet, AD2 in the switchyard, which when activated steers the extracted proton beam into the A Line to the MECO experiment.

Magnet	Type	Gradient(kG/cm)	Current (A)	Power Supply (KW)
BQ5,8	4Q16	-1.502	400	14.43
BQ6,7	4Q16	1.103	300	8.12
BQ 9a,b	4Q16	1.209	300	8.12
BQ10	8Q32	0.9634	250	5.21
BQ11	8Q48	-0.4675	1000	36.00
BQ12	5Q36	0.2191	150	2.20
BQ13	5Q36	1.311	1000	97.50
BQ14	3Q48	-2.111	2400	74.88

Table1. Primary Beam Quadrupole Magnets and Power Supplies. The magnet designations indicate the aperture in inches with the first character and the length of the steel by the last two, also in inches. Power supplies for CQ5-8 are presently connected to the appropriate magnets.

Magnet	Type	Field(kG)	Current(A)	Power Supply (KW)
BD3	18D36	11.13	1575	92.96
BD4	3.5X7D92	5.81	1500	13.50
BD5-8	3X4D78	10.70	3000	54.00
BP				

Table 2. Beam Dipole Magnets and Power Supplies. Power supplies for BD5-8 are presently connected to the appropriate magnets.

Magnet Type	Magnetic Field	Integral(kGm)	Current(A)	Power Supply(KW)
B1D1	Special Design	BD1+BD2=37.7	1470	450
B1D2	Special Design		3065	620
B1D3	Special Design	5.7	3000	1,300
B1D4	Modified 48D48 3m Gap & Booster Coils	1.5-2.1	3000 + 2000	1,000

Table 3. Neutral Beam Sweeping Magnets and Power Supplies. The B1D4 booster coils on operate at different currents.

2. Production Target

The water-cooled production target concept is illustrated in Figure 4. The platinum target is positioned by a series of thin clips in a water-jacket supported from an overhead shielding block through which cooling water piping and wiring for temperature monitoring instrumentation pass. The overhead shielding section of the target assembly is designed to complete the roof shielding and has water and electrical disconnect fittings at the top.
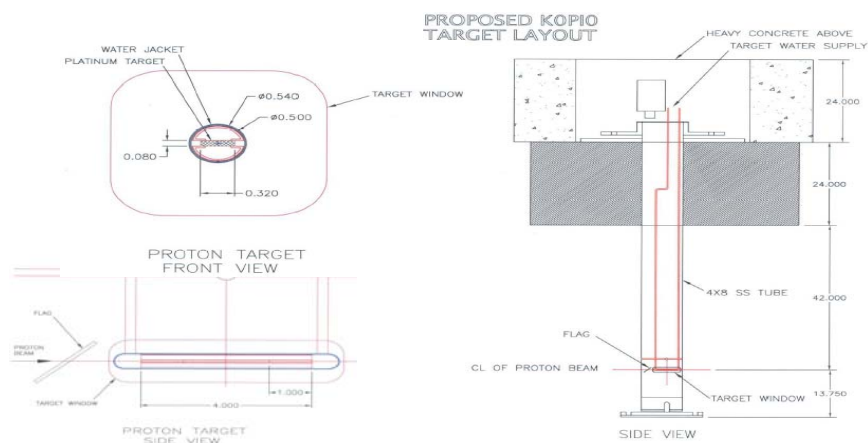

Figure 4. Water Cooled Target Assembly.

The target is supported from a shielding block above by water carrying tubes which are braced

by connection to the 0.5mm thick cylinder wall. The target is positioned in the center of the 1.27mm I.D. water jacket by a series of thin spring clips. The entire assembly can be removed as a unit, placed on top of a shielded enclosure surrounding the target, and moved to a storage area in the event of a failure. An aluminum oxide flag inclined at 45 degrees allows observation of the fluorescent image of the beam spot by a shielded video camera viewing the flag through a mirror. The target is contained in a 316L stainless steel alloy container with a wall thickness of 0.5 mm to minimize beam interactions. The simulations predict a water flow of 3.2 gallons/minute will result in an output water temperature of 85 degrees F.

The GEANT calculated longitudinal distribution of energy deposition in a 4mm diameter platinum target. The temperature distributions within the target as well as at its surface were simulated using the ANSYS 6.0 code are displayed in Figure 5. The target was divided longitudinally into four segments for stress relief arising from thermal expansion. A stress analysis was also carried out.
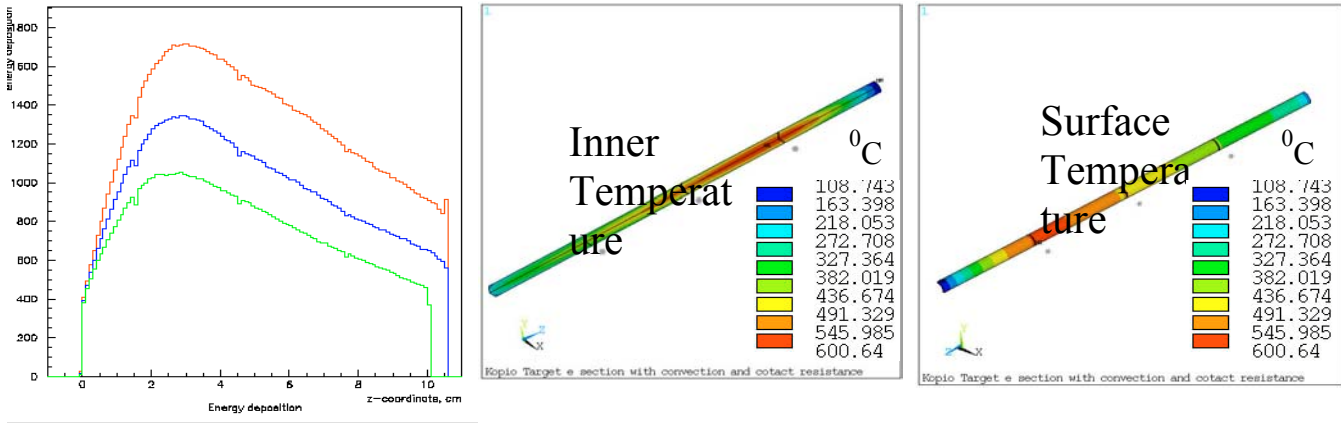

Figure 5. GEANT calculations of the energy deposition in GeV/mm/10^5 protons for 2, 3 , 4, diameter Beams respectively and the peak temperature distributions inside and on the surface of the production target.

3. Shielding /Beam Dump

Figure 6. Layout of the KOPIO beam line and shielding

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The primary beam sidewall and roof shielding consists of 3m of heavy concrete or substituting the equivalent steel plate for some of the concrete, figure 6. The primary beam dump is 31 meters of steel in a cavity in which the beam is initially incident on a concrete block which attenuates residual beta and gamma radiation. This shielding can be found in stock or decommissioned beam lines. The beam dump begins 20m downstream of the production target in order to minimize its contribution to the neutron background at the experiment.

4. Secondary Beam

The secondary beam consists of a collimator system centered about a horizontal production angle of 42.5 degrees and defines the 100 mr (horizontal) by 4 mr (vertical) acceptances. Two radiation hard sweeping magnets pitch the charged component of the beam, in particular e^+e^- pairs emanating from a 7 cm thick photon converter ("spoiler") which removes the gammas originating in neutral pion decay, vertically out of the acceptance. Conceptual design drawings of the upstream sweeping magnets, developed with 3-dimensional magnetic field simulations using the OPERA program and the horizontal component of magnetic field along the beam axis are shown in Figure 7, the ordinate is given in Gauss and the abscissa in cm. The simulated integral field of 3.37 Tm exceeds the requirement.
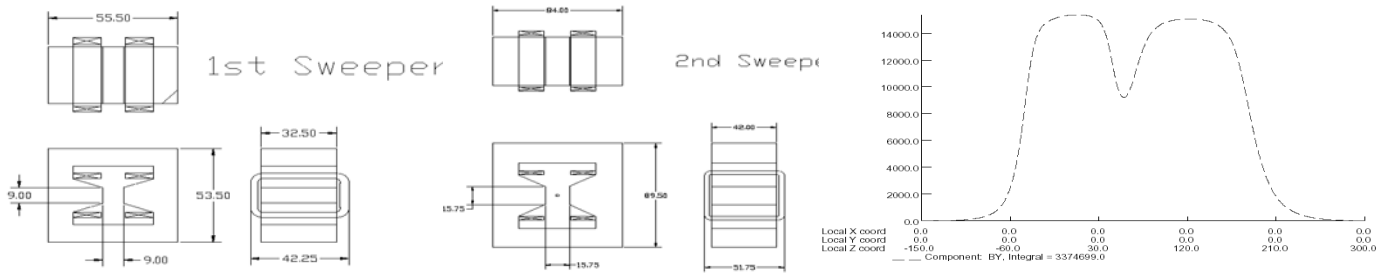
Figure 7. The Schematics of magnets D1 and D2 and the horizontal component of the magnetic field of the pair on beam axis.
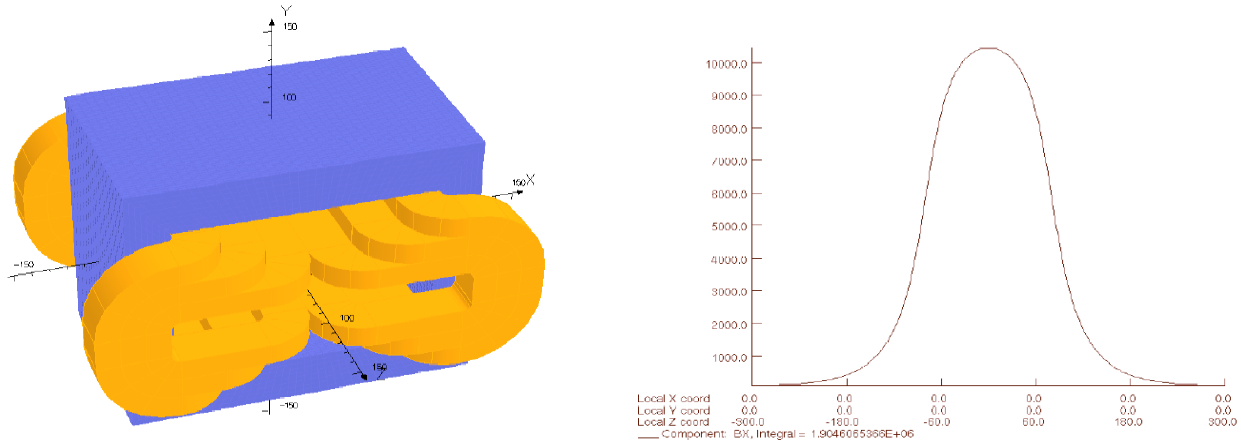
Figure 8. Conceptual design of sweeper magnet D3 and the horizontal component of the Magnetic Field on axis.

A third sweeping magnet is planned for the region between the last collimator and the upstream photon veto wall to remove remaining charged particles before the beam enters the fiducial region. An integral field of 1.9Tm of over 2m has been specified. The beam divergence implies a gap of 1.5m to accommodate the vacuum enclosure. As in the case of the fourth sweeping

magnet, using a 48D48 spectrometer magnet with the gap opened from .47m to 1.5m by means of backleg shims was considered but the large fringe field would be have to be greatly reduced at the upstream veto wall. A preliminary alternative magnet design has been modeled with OPERA and the calculated horizontal component of magnetic field is on the axis is plotted in Figure 8.

The fourth sweeping magnet is located immediately downstream of the calorimeter array in order to deflect charged particles from decays into the charged particle veto counters. A 48D48 spectrometer magnet with its gap opened to 3m and turned on its side to produce a vertical deflection, has been modeled with a 10cm thick iron field clamp on the upstream side of the magnet in order to reduce the fringe field at the photomultiplier tubes of the pre-radiator, the charged particle veto counters and the photon barrel calorimeter locations 2m upstream of the iron plate. A peak field of 0.21T was obtained with an integral of 0.57Tm. The field clamp was calculated to reduce the field to 20G in the area of concern. Figure 9 shows D4 with its field clamp and the field plot. The off axis field is still smaller.
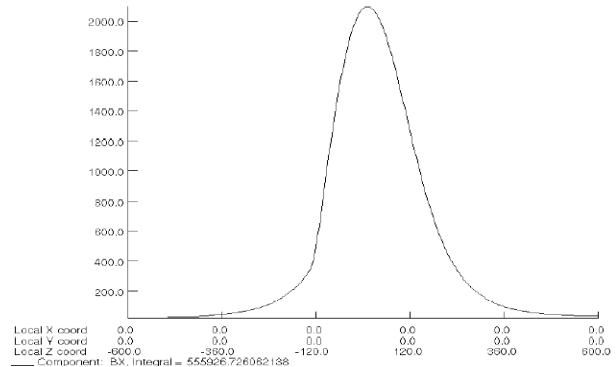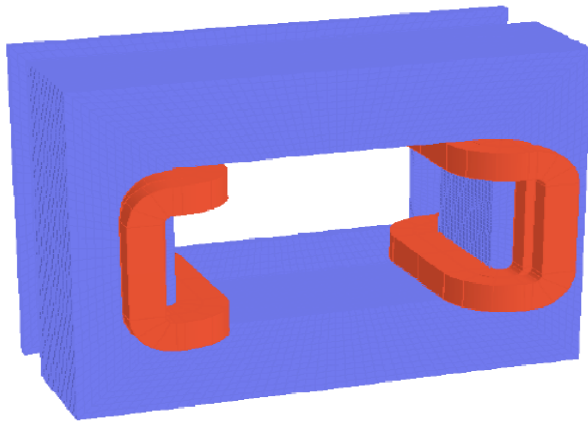
Figures 9. Conceptual design of sweeper magnet D4 and the horizontal component of Magnetic Field on axis.

The collimator design requires that the first aperture, which defines the neutral beam acceptance, shields the subsequent collimator apertures from particle trajectories originating in the production target. The defining apertures of the four collimators are tungsten or HEVIMET inserts in 4mx4m steel walls of 1m thickness which will be tapered to match the divergence of the calculated beam envelope. The horizontal and vertical collimator configurations are displayed in Figure 10. The 50 cm gaps between individual collimators are to be filled with borated concrete. In addition to the large neutron capture cross section for neutrons that have been thermalized by collisions with the protons in the
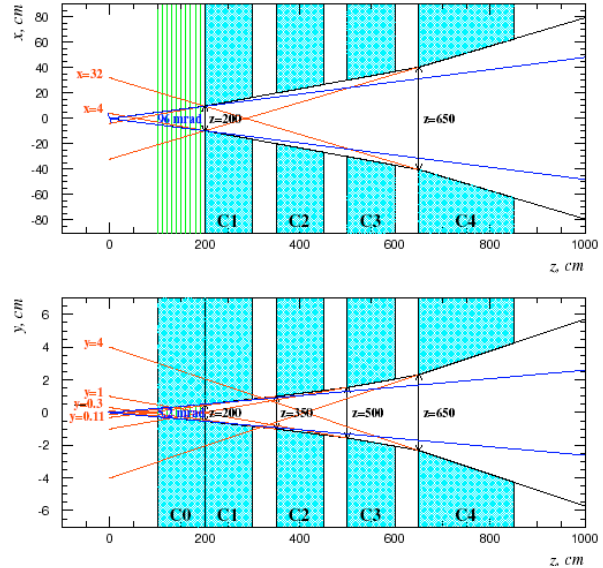

Figure 10. Collimator geometry. The C0 collimator limits only the vertical acceptance

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water component of the concrete, boron also emits an alpha rather than a 5 MeV gamma which is typical of neutron capture in nuclei. MCNPX simulations have demonstrated the effectiveness of hydrogenous material in reducing neutron ambiance in the collimator array.

The threshold for neutral pion production by neutrons is 750 MeV/c. Background simulations have demonstrated that because the gammas resulting from neutral pion decays are the event signature, the halo of neutrons of 750 MeV/c outside the beam envelope must not exceed a level of 10^{-5} of the beam intensity. Employing neutron spectra from the water cooled platinum target obtained with the MARS program, simulations with GEANT and FLUKA, that were used in the collimator system design, have shown that the 10^{-5} limit on halo can be maintained, figure 11.

Figure 11. MCNPX Results for Neutrons as a Function of Depth in the Collimator Array. The data is given in neutrons of less than 20 MeV/cm^2 per incident proton on target as a function of depth in the collimator array. The data points are given at points behind each of four 1m thick Pb collimators separated by 50cm with a conical aperture whose axis is at 45 degrees to the production target. The data points indicated by X were obtained with polyethylene filling the spaces between the collimators whereas those represented by + were obtained for empty spaces.
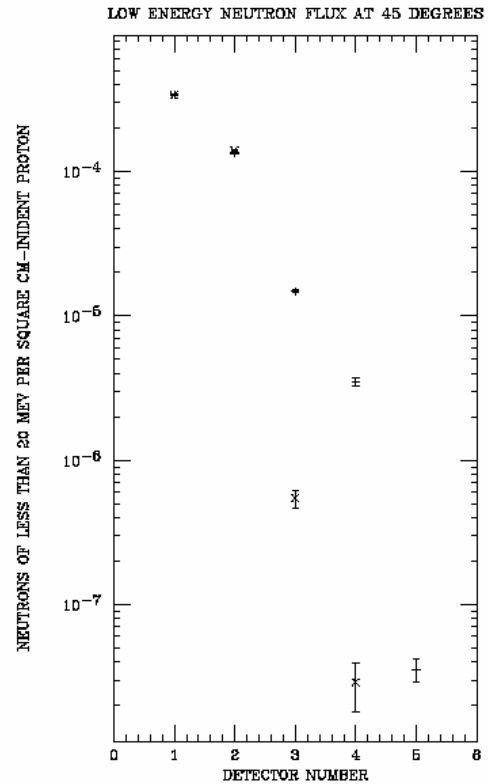
The small vertical acceptance of the collimators necessitates accurate alignment of the collimators relative to both to each other and to the production target. The simulations indicate that vertical misalignments of a few mm can lead to a large increase in neutron halo.

A possible approach to maintaining a tolerance of 1mm would be to mount the neutral beam components, i.e. the collimators and sweeping magnets, on a steel plate of sufficient thickness to insure vertical alignment of better than 1mm between the individual collimators. The production target assembly would incorporate a precision vertical adjustment in order to maintain alignment with the collimator axis, figure 10. Vertical and horizontal trim magnets in the downstream section of the proton beam line will allow the beam position on the production target to be optimized.

5. Vacuum

KOPIO requires a vacuum of 10^{-7} Torr in the neutral beam and event detection region. Cryogenic pumps were chosen for this purpose although turbo molecular pumps will also be needed to bring the pressure below 10^{-3} Torr where the cryo pumps become effective. Because of the importance of the collimation system performance in reducing beam halo, it was decided to configure the vacuum piping by means of a large manifold in a trench below the collimators connecting to the beam pipe via three 25cm diameter vertical pipes between collimator elements that are transversely staggered along the beam so as to minimize displacement of the borated

concrete between the collimators.

The downstream beam pipe vacuum need only be in the microtorr range and will be separated from the upstream region by a 150 micron thick aluminized kapton window immediately downstream of the calorimeter. Bypass plumbing and vacuum sensors will allow the two sections of beam pipe to be simultaneously pumped down to the microtorr range with minimal pressure differential.

6. Experimental Installation

A pit of 2.5 to 3m depth must be provided to allow full detector coverage of the experimental acceptance and access to the pre-radiator on-board electronics, the calorimeter readout, photon veto barrel and photon veto wall as a consequence of the beam height of 2m above the floor.

A prefabricated structure with power and air conditioning will be erected adjacent to the east shielding sidewall of the experimental area for fast electronics for processing detector signals and triggering. The counting house originally built for E802 and successor experiments in the B Line will be used by the KOPIO collaboration.

A platform for power supplies for the calorimeter electronics and some signal processing will be installed above the calorimeter array.

7. Secondary Beam and Experimental Area Shielding

One meter of light concrete has been estimated as sufficient for side wall shielding and covering the top of the neutral beam. The effectiveness of 1m of steel and 2m of light concrete for a beam was calculated with the MCNPX code. A meter of heavy concrete roof over the beam catcher is necessary because of the fraction of the 10^{11} neutrons in the beam interacting in 50 mm of Pb converters in the catcher.

8. Access Control System

``Controlled Access" to the B primary beam cave between the switchyard and the KOPIO will be through an outer gate which will involve use a personal card, the upgraded iris scanner, key tree and video monitoring system that has come into use at the AGS, RHIC and the NSRL in recent years. The production target area will be accessed through an additional internal gate with a special key because of the very high residual radiation levels present.

The experimental area will be accessed through upstream gates on either side of the pit area in which the preradiator, calorimeter and barrel veto are located and two separate gates providing access to the downstream veto counters and the beam catcher. Access control similar to that for the primary beam cave will be used unless experimenter controlled access and sweep is approved for the upstream area by the C-A Department Radiation Safety Committee.

Chapter IV. ESHQ

1. Purpose of the ESHQ Chapter

This chapter briefly describes the rigorous safety and environmental protection activities associated with the RSVP Project that will be completed prior to commencement of construction, commissioning, operations and post-operations.

1.1 Process or Activity Descriptions

Both the MECO and KOPIO beam lines and experiments will utilize high intensity beams, new state of the art detector systems (calorimeters and wire chambers), large conventional magnets (KOPIO sweepers), large bore superconducting magnets (MECO PS and DS), and large decay volume structures under vacuum (KOPIO). These have been described in detail in the KOPIO and MECO CDRs and in earlier chapters.

Take for example, the decay volume and the entire beam path within the view of the detector must be at high vacuum, about 10^{-7} torr, in order to suppress background from neutron and K^0 interactions with the residual gas. KOPIO is pursuing a carbon fiber or aluminum vessel for the decay vacuum system. Using this non-standard technology may introduce unknowns in the design and fabrication. For the KOPIO vacuum decay system, a Failure Mode and Effects Analysis of entire system will be performed along with testing of a scale model.

The KOPIO detector pit is designed approximately 135 m^2 in area by 3.3 m deep. It is positioned from the exit of the neutral beam collimator to the downstream exit of the sweeping magnet. Two 1.3 m wide by 1.3 m deep utility trenches will connect the detector pit to the west EEBA man trench in Building 912. Safety railings, access ladders, ODH provisions, and flammable gas detection will likely be needed for the pit. ODH issues also surround the MECO superconducting magnets.

With regard to the protection of groundwater from tritium contamination, the accelerators will need additional protection due to a combination of high-intensity beam operations and a very low level of contamination now allowed at the BNL site. Present plans call for an impermeable rain water barrier to be installed over all areas of the AGS and Booster Rings where beam losses may activate the soil resulting in leached water above 5% of the Drinking Water Standard for tritium or sodium-24. This will be done in conformance of BNL's SBMS requirements.

Two methods of installing the impermeable barrier are presently being considered. The specific type of impermeable barrier will depend on the terrain over these accelerators. One method is to use a High Density Polyethylene Membrane (HDPM) placed about 0.7 m below grade, similar to the caps installed over landfills. The second method is to install a cap over the earth shields covering the accelerators, using reinforced Gunnite or concrete. Gunnite is a material used to form swimming pools. Each of these methods has been used successfully in the past over portions of the Booster, AGS and RHIC earth shields. The maximum cap coverage area still needed for the AGS earth shield is about 11,000 m^2 and for the Booster earth shield about 2,200 m^2.

1.2 Inventory of Hazards

Ionizing Radiation –The Linac, AGS and Booster enclosures are High Radiation Areas. These accelerators would be expected to have residual radiation levels between 0.1 and 10 rem per hour after a running period with high-intensity protons. With the exception of the primary beam lines and target caves in Building 912, most of Building 912 is a Radiation Area. The residual radiation level in routinely occupied areas in Building 912 when these experiments are not running would be less than 0.5 mrem per hour in most areas. During running periods, Building 912 levels are expected to range between 1 and 20 mrem per hour in accessible areas, particularly near cable trenches and other penetrations into the primary beam lines. Residual radiation levels inside the primary beam line enclosures and target caves would be similar to that in the AGS Ring, about 0.1 to 10 rem per hour, although the targets themselves may range up to several hundred rem per hour at 30 cm. Direct in-beam exposure to primary and secondary beams may be as high as several terarad per hour; thus, primary and secondary beams would be fully enclosed and not accessible. By design, fault levels in accessible areas due to unanticipated beam loss would be less than 20 mrem per fault.

Non-ionizing Radiation - High power, 24 kW, RF systems that generate large fields of electromagnetic radiation in the frequency range of a 740 kHz will be present. Alignment lasers will be used in the experiments. Laser light systems to feed light into experimental detector systems will be used. Lasers will be used for calibration and timing checks on experimental detectors.

Hazardous or Toxic Materials - Although the dominant shield materials are concrete, copper, tungsten and iron, lead shielding may be used in limited amounts to shield against residual radiation when High Radiation Areas must be occupied. Beryllium windows and lithium-doped cylinders will be used. Lead-tungstate crystal, bismuth germinate or $Bi_4Ge_3O_{12}$ will be used. Hazardous chemicals will include cleaning agents and cooling-water treatment chemicals.

Radioactive Materials – Various low-level radioactive materials will be present in the nearby shielding, beam stops, primary beam-line equipment and accelerator equipment due to activation from high-energy hadrons. Typically, the embedded nuclides are ^{60}Co, ^{22}Na and ^{3}H, and they are found in pCi/g quantities. High levels of residual radioactivity will be contained in primary targets that are made of tungsten, gold or platinum; levels will be on the order of several hundred Curies. These targets will decay rapidly by about a factor of 5 within a few days. Low-level, about 20 μCi, radiation sources such as ^{60}Co or ^{137}Cs will be used for detector testing.

Fire - Welding gases and flammable/explosive gases may exist during construction or during repair periods. Detectors such as the MECO straw detector represent significant combustible loading. Flammable detector gases may be used in some experimental detector systems. Lucite and scintillator materials used in photon detectors represent combustible loading.

Electrical Energy - Electrical hazards such as electrical shock and arc flash will be present. High voltage and high current systems will be used. Equipment is normally de-energized prior to work.

Oxygen Deficiency - The cryogenic system for the MECO superconducting solenoids contains cryogenic liquids, such as helium, that can be released. The pit in the KOPIO experiment may represent an ODH if argon-ethane gas is used in the contiguous detectors.

Kinetic Energy - Kinetic energy hazards associated with motorized materials-handling-equipment and with the operation of hand and shop tools will exist. Superconducting solenoids containing super-cooled liquids have the potential to suffer a local instantaneous heat load that could trigger quenching.

Potential Energy - High magnetic fields, up to 5 Tesla, will be present and loose, ferrous objects will have to be located at a safe distance from the superconducting solenoids. Potential energy hazards such as those associated with compressed gases and vacuum vessels, as well as those associated with hoisting and rigging operations will exist. Potential energy hazards due to working at heights, either from scaffold structures or trenches or pits, will be present.

Thermal Energy - Heat sources such as soldering irons and vacuum heating blankets will exist. Primary-beam targets will be significant sources of heat.

Cryogenic Temperatures - Skin contact with cryogenic materials due to spills or splashes may cause freezing or "cryogenic burns."

Soil Activation – Due to the use of high intensity proton beam, soil activation is possible throughout the acceleration path and the transport path of the primary proton beam. Unless controlled with caps, soil activation will lead to groundwater contamination.

Gaseous Radioactive Emissions – Cooling fluids and cryogenic fluids near targets will be activated by primary and secondary beams, and produce emissions on the order of several mCi per year of ^{11}C and ^{13}N, and µCi per year levels of tritium.

2. Preliminary Hazard Analysis (PHA)

An initial review of environmental, safety and health issues related to RSVP facilities leads to the conclusion that fire, ionizing radiation, laser, RF radiation, oxygen deficiency and electrical hazards require further safety analysis, an analysis that considers the hazards and controls in detail.

The Collider-Accelerator Department and Brookhaven National Laboratory have specific programs that RSVP, BNL and C-AD staff must comply with in order to identify, analyze, design-out and/or control these hazards. For example:

- Accelerator Safety Subject Area
- Accelerator System Safety Committee Review
- Authorization
- ALARA Committee Review
- Cryogenic Safety Sub-Committee Review
- Conduct of Operations

- Design Practice for Known Beam Loss Locations
- Electrical Safety at C-AD
- Environmental Management System
- Experimental Safety Review Committee
- Facility and Area Risk Assessments
- Facility Specific Training
- Hazard Screening Tool
- Job Risk Assessments
- OSH Management System
- Process Evaluations for Environmental Aspects
- Radiation Safety Committee Review
- Work Controls for C-A Staff

In general, the following specific occupational safety and health techniques will be used in the order listed in order to reduce or eliminate the potential risks associated with construction and operation of the RSVP facilities:

- Eliminate the hazard/risk
- Control the hazard/risk at source, through the use of engineering controls
- Minimize the hazard/risk through the use of safe work systems, which include administrative control measures such as check-off lists and work permits
- If residual hazards/risks cannot be controlled by the above measures, then use appropriate personal protective equipment, including clothing

Emergency issues will be addressed in the C-A OPM 3.0, Local Emergency Plan for the C-A Department.

Prior to work in RSVP facilities, key competency requirements are required to be met by technicians, scientists, guests and sub-contractors. A job training assessment (JTA) will be performed for every job category. Specific training will be listed in each person's training record, and training requirements will be checked by the Work Control Coordinators.

The shielding policy for this facility is the same as that for the rest of the Collider-Accelerator facilities since the RSVP facilities are to be the responsibility of the Department. Specifically, the Collider-Accelerator Department's Radiation Safety Committee will review facility-shielding configurations to assure that the shielding has been designed to:

- Prevent contamination of the ground water
- Limit annual site-boundary dose equivalent to less than 5 mrem
- Limit annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities to less than 25 mrem
- Limit dose equivalent to any area where access is not controlled to less than 20 mrem during a fault event
- Limit the dose equivalent rate to radiation-workers in continuously occupied locations to ALARA but in no case would it be greater than 0.5 mrem in one hour or 20 mrem in one week
- Limit the annual dose equivalent to radiation workers where occupancy is not continuous to ALARA, but in no case would it exceed 1000 mrem

In addition to review and approval by the Radiation Safety Committee, final shield drawings must be approved by the Radiation Safety Committee Chair or the ESHQ Associate Chair. Shield drawings are verified by comparing the drawing to the actual configuration. Radiation surveys and fault studies are conducted after the shield has been constructed in order to verify the adequacy of the shield configuration. The fault study methodology that is used to verify the adequacy of shielding is proscribed and controlled by Collider-Accelerator Department procedures.

Significant environmental aspects of the RSVP Project include:
- Sole Source Aquifer
- Excavation Within Building 912
- Chemical Storage/Use
- Liquid Effluent
- Hazardous Waste
- Radioactive Waste
- Radiation Exposures
- New or Modified Federal/State Permits
- Soil Activation and Groundwater Contamination with Tritium

Although BNL is situated over a Sole Source Aquifer, operation of the RSVP facilities should not affect the aquifer. This would include discharges to the BNL sanitary and storm water systems. The BNL Standards Based Management System Subject Area Liquid Effluents provides requirements related to discharges. Work planning, design review, and safety inspections are three examples of several C-AD methods used to ensure hazardous effluents would not make their way into the sanitary waste-stream or storm-water discharges.

Excavation would be required to install the KOPIO experimental pit inside Building 912. Excavation would be limited to the area immediately inside the existing experimental building. Soil removed from this area would be checked for activation and handled in accordance with established C-AD procedures and BNL Subject Areas.

Routine operation and maintenance actions associated with these facilities would involve the use of chemicals or compounds, generally in small quantities. BNL's Chemical Management System would track the quantity, location, owner and storage of any chemical inventory.

Any discharges associated with the RSVP facilities, including cooling-tower effluent, would be managed according to the BNL Standards Based Management System Subject Area Liquid Effluents.

Routine operation and maintenance actions associated with RSVP facilities would result in a small amount of hazardous wastes being generated, primarily cleaning compounds. The total volume generated would not be expected to exceed a few tens of cubic feet per year and would not constitute a significant increase to Collider-Accelerator Department total estimates. All hazardous wastes would be managed in accordance with established C-AD procedures and BNL Subject Areas.

Routine operation and maintenance actions associated with RSVP facilities would result in a moderate amount of radioactive waste being generated. The total volume generated would not be expected to exceed a few hundred cubic feet per year and would not constitute a significant increase to Collider-Accelerator Department total estimates. All radioactive wastes would be managed in accordance with established C-AD procedures and BNL Subject Areas.

Routine operation and maintenance actions associated with the RSVP and associated accelerator facilities would result in low-level radiation exposures to workers. Interlocks, access controls, training and procedures would be used to minimize exposures and employ ALARA principles.

Because portions of the affected area are within the one-half mile corridor of the Peconic River and are proximate to wetlands, BNL would submit to the New York State Department of Environmental Conservation an application for permit under the Wild, Scenic and Recreational River Systems Act. Depending on the disposition of cooling-tower discharges, the existing New York State Pollutant Discharge Elimination System (SPDES) permit would be revised as necessary.

Any proposed cooling-water systems for the RSVP facilities would be closed-loop de-ionized water systems using ion exchange beds that would be removed for regeneration or disposal by a contractor off-site. At the proposed beam currents and energies, low-level induced radioactivity would be expected in cooling water exposed to primary and secondary beams. This water would be collected and handled according to approved waste practices. Discharge of radioactive water or contaminants to the ground or to the sanitary system would be neither planned nor expected from the RSVP cooling systems. Closed-loop cooling systems would be connected to a cooling tower via a heat exchanger. Cooling-tower waters would be treated either with ozone or with biocides and rust inhibitors, and would meet all SPDES effluent limits.

It is noted that high-energy protons and other high-energy particles emerging from beam loss areas are eventually scattered or absorbed in earth shielding. Typical long-lived radioactive atoms created in soil shielding by the activation process are tritium (^{3}H), with a half-life of 12.3 years, and sodium-22 (^{22}Na), with a half-life of 2.7 years. The C-AD Department will place permanent water-impermeable caps over the Booster and AGS tunnels in order to prevent rainfall from leaching these activation products from the soil shielding into the groundwater. It is noted that a large 5-acre concrete apron extends throughout Building 912, and this apron protects the soil beneath the experimental areas. Direct activation of the groundwater has been examined near the KOPIO pit area and sufficient shielding will be used to prevent contamination of the groundwater.

3. ESHQ Plans for Construction by RSVP/C-AD/BNL Staff and by Sub Contractors

Portions of the RSVP project will be constructed by RSVP/C-AD/BNL staff and portions by sub-contractors, most notably the caps for the AGS and Booster accelerators. All requests for goods or services will be processed through a formal and well-documented system of review to incorporate any special environmental, safety or health requirements of the contractor or vendor. For both sub-contractors and RSVP/C-AD/BNL staff, all work or contracts will be reviewed using the requirements in the BNL Subject Area Work Planning and Control for Experiments

and Operations. The drawings for the RSVP Project will be sent to the BNL's Safety and Health Services Division for review by the appropriate ES&H disciplines.

C-AD will define the scope of work with sufficient detail to provide reviewers and support personnel with a clear understanding of what is needed, expected, and required. For sub-contractors, this will include the type of work to be performed, location of work, defined contract limits, allowed access routes, and any sensitive or vulnerable Laboratory operations or infrastructure that may be impacted by this work.

The C-AD will ensure that facility hazards are characterized and inventoried specific to the expected construction location and activities.

The C-AD will ensure that minimum ES&H competency requirements for contractors and RSVP/C-AD/BNL staff are detailed. For sub-contractors, these requirements will be provided to the Procurement & Property Management Division (PPM). PPM will include those requirements in the bid and contract documents to qualify contractors for award. Competency requirements will be consistent with the project, facility and job to be performed.

Candidates for contract award will be required to submit the following:

> *Comprehensive Corporate Environmental, Safety and Health Program* - Candidates for contract award must submit an acceptable Corporate Health and Safety Program to be considered for award. This program must be sufficiently detailed to clearly define ES&H responsibility, accountability, and authority of the company's employees for the intended work to be performed and the hazards to be encountered.

> *Performance History* - Injury/Illness reports for the previous three years and environmental compliance record for the latest 5-year period would be submitted.

> *Complex or Hazardous Activities* - For projects involving complex or hazardous activities, submission of equivalent project experience, hazard-specific management programs, resumes and related work histories of field and supervisory personnel will be required. In addition, copies of any required certifications, registrations or applicable County, State, or Federal Permits must be submitted.

> *Administration* - Personnel responsibilities will include the obligation to obey the safe working practices for their trade, the frequency and scope of inspections for deficiencies, corrective actions to be taken, reporting of accidents, injuries, near-misses, spills, and leaks.

> *Enforcement, Reporting, and Evaluation* - Corrective action will be clearly defined with abatement and punitive actions outlined. The reporting and record-keeping process will be outlined with specific responsibilities for notifying BNL, contractor, and regulatory personnel, documenting the deficiency and its abatement.

> *Project Environmental Safety and Health Plan* - The contractor will be required to submit a project safety plan that complies with the requirements of the Federal Acquisition Regulations, BNL SBMS Requirements and 29 CFR 1926 Safety and Health Regulations for Construction.

The C-AD will ensure only authorized personnel are allowed on the Laboratory property to perform work. They shall carry current BNL issued gate passes, identification badges, or be escorted by an authorized Laboratory employee. To obtain access, contractor employees and non-BNL RSVP personnel must have received BNL and C-AD site-specific training or be assigned an escort.

Materials to be disposed-of, recycled or otherwise reused either on or off-site, shall pass through the vehicle radiation monitor in the presence of a Radiological Control Technician or equivalent.

The RSVP job site will be inspected with sufficient frequency to accurately assess compliance with ES&H obligations, and to identify any weaknesses in ES&H management of the site. Violations of ES&H requirements shall be cause for a work interruption on that portion of the work, and may be grounds for a Stop Work Order for the entire project. Inspections will be documented. Records will be kept of hazards and the corrective actions taken.

Imminent danger, or failure to adequately correct identified safety deficiencies in a timely manner will be cause for a Stop Work Order to be issued on part or the entire project. The Stop Work Order can only be lifted when the C-AD or the contractor has prevented or controlled the identified hazards, and corrected the ES&H management system deficiencies that allowed them to occur.

All accidents, injuries, illnesses, environmental hazards, imminent danger, and near-misses will be reported to the appropriate BNL authority immediately. Investigation and reporting will be in compliance with BNL SBMS requirements.

Fire, accidents involving injury, illness or property damage, injury or illness of unknown origin, any quantity of pollutant dropped anywhere, the suspicion or discovery of munitions will require immediate notification of BNL Emergency Services (x911).

Contractor employees will be required to maintain current permits for the activities being performed at the jobsite.

4. ESHQ Plans for Commissioning, Operations and Post Operations

The Collider-Accelerator Department (C-AD) will identify hazards and associated on-site and off-site impacts to the workers, the public and the environment from the RSVP facilities for both normal operations and credible accidents. Although C-AD will not list and describe every hazard at the RSVP facilities, sufficient detail will be provided to DOE to ensure that C-AD has performed a comprehensive hazard and risk analysis. The amount of descriptive material and analysis will be related to both the complexity of the facility and the nature and magnitude of the hazards. In addition, C-AD will provide an understanding of radiation risks to the workers, the public and the environment.

The C-AD will provide appropriate documentation and detailed description of engineered controls, such as interlocks and physical barriers, and administrative measures, such as training, taken to eliminate, control or mitigate hazards from operation. The C-AD will demonstrate that controls are sufficient to satisfy requirements and manage identified conditions associated with

hazards. C-AD will document the methods used to mitigate the hazards to the extent prescribed by applicable requirements, codes or consensus standards.

The C-AD will describe the Department management organization, and the function and location of each RSVP facility in addition to details of major components and their operation. The descriptions will be of sufficient depth and breadth that a reviewer familiar with accelerator operations but unfamiliar with a particular RSVP system can readily identify potential hazards and populations or environments at risk.

The ESHQ analysis will address the hazards of all the systems within the purview of the RSVP operations. It will cover all facilities such as injectors, accelerators and experimental areas in Building 912.

The ESHQ analysis will follow the generally accepted principles that include:

1. A description of the function of the integrated RSVP facilities and the protection afforded the public and worker's health and safety, and the protection of the environment.
2. An overview of the results and conclusions of the ESHQ analysis including a description of the comprehensiveness of the safety analysis and appropriateness of the Accelerator Safety Envelope.
3. A review of the land, water, air and wildlife environment within which the RSVP facilities operate, individual facility characteristics that are safety-related and the methods to be used to operate the accelerators, the beam-lines and the experiments. The following items will be addressed either directly or by reference to an existing current safety analysis:
    • Site geography, seismology, meteorology, hydrology, demography and adjacent facilities that may affect or may be affected by the RSVP facilities
    • Design criteria and as-built characteristics for components with safety-significant functions
    • Features that minimize the presence of hazardous environments such as those that ensure radiation exposures are kept ALARA during operation and maintenance
    • BNL and C-AD organizational and management structures and a delineation of responsibilities for safety, health and environmental protection
    • The function of engineered and administrative controls both for routine operation and for emergency conditions
    • Critical operational procedures to prevent or mitigate accidents
    • Design criteria and characteristics of experimental equipment, systems and components having safety-significant functions
4. The safety analysis, including the systematic methods used to identify and mitigate hazards and risks, will be documented. Hazardous materials, energy sources and potential sources of environmental pollution including radiological hazards will be characterized and quantified. Coupled with the identification of hazards will be a description of the controls that are employed for their mitigation. The description of controls will include discussion of credible challenges and estimates of consequences in the event of corresponding failure. A discussion of the risk to workers, the public and the environment from radiation will be included. In addition, the methods to ensure radiation

exposures are kept ALARA during operation, maintenance and facility modification will be described.

5. An Accelerator Safety Envelope will be developed for RSVP commissioning and operations and will consist of the engineered and administrative bounding conditions within which the BNL and C-AD will operate the RSVP facilities.

6. A quality assurance program will be applied at the RSVP facilities, focusing upon activities that influence protection of the worker, the public and the environment.

Post-operations activities normally include a transition period, followed by deactivation, decommissioning and remedial surveillance activities. These activities will likely require development of a written plan that meets whatever requirements are in place at the time of post-operations. This plan will incorporate budget and schedule realities.

These RSVP facilities are large and complex and could contain radioactive and/or hazardous substances long after termination of operations. The post-operations plan will be developed by BNL when RSVP facilities complete their mission and are declared excess. The RSVP facilities will then pass into a transition period where they are ultimately prepared for disposition. The disposition period of RSVP's life-cycle may include deactivation, decommissioning, and surveillance and maintenance activities.

As part of the post-operations plan, specific end-points will be agreed upon by the applicable regulators and stakeholders. End-points are the detailed specifications of conditions to be achieved for the RSVP space, systems, and major equipment.

BNL will ensure that surveillance and maintenance activities for RSVP post operations are adequate to maintain the Accelerator Safety Envelope during the final stages of operations through a seamless transition to the final disposition of the facility.

Post-operational activities will likely be facilitated by using a modular approach. The overall post-operations plan will likely be prepared as separate plans focused on discrete logical modules of the RSVP facilities such as injectors, targets, experiments, or experimental buildings rather than a single document addressing the entire RSVP program.

Requirements that apply to post-operations activities will be identified in the post operations plan. Requirements may originate from several sources, including regulatory requirements, contract obligations, internal BNL and C-AD procedures, and formal commitments made by BNL management. Requirements will also address appropriate LOTO of equipment, hazardous chemical and radioactive material storage and/or disposal, periodic surveillances to verify continuing safe conditions, and physical security measures to prevent unwanted public access.

C-AD will collect and retain records on appropriate aspects of RSVP operations that may be needed to facilitate decommissioning or return of the accelerator site to other uses. Types of records that will be considered for long term retention to facilitate post-operational activities will include items such as:

▪ Records documenting the use, storage, and disposition of regulated or hazardous chemicals or of radioactive materials

- Records documenting routine and non-routine facility releases of radioactive or hazardous materials
- Records documenting parameters (e.g. beam intensity, repetition rate, pulse length, beam energy, etc.) that would facilitate assessments of the extent of activation of items such as shielding, components and adjacent soils
- Records documenting routine and non-routine contamination events including decontamination efforts and long-term residual contamination

Operations at adjacent C-AD facilities may be ongoing concurrent with RSVP post-operational activities. C-AD will consider the potential impact from those operations as well as impacts to those operations by any post-operational RSVP activities. These considerations will include:
- Safety impacts including radiation burdens, ODH hazards, etc. from adjacent operations
- Possible disruption of safety systems shared between facilities, e.g. fire alarm system
- Structural impacts including alignment and stability of nearby structures or equipment
- Operational impacts including disruption of access or services to adjacent operations or restrictions on access and services caused by adjacent operations

Detailed records from operations as well as records of post-operations activities will be archived for proper long-term retrieval consistent with applicable regulations, e.g. DOE O 200.1, Information Management Program.

Chapter V. The PASS System

1. Introduction

Particle Accelerator Safety System (PASS) provides an integrated system for protection from potential radiation and oxygen deficiency [ODH]. The general design approach will be described, then the overall architecture of the system and that of the independent sub-systems.

2. General Characteristics

In order to provide radiation protection compliant with DOE 5480.25, PASS is required to prevent beam in the area by two independent devices [Critical Devices] during any area entry, provide dual independent area entry detection during beam operation and dual independent control logic. In addition PASS assures that there are no personnel in the area when beam is enabled to that area with the use of monitored sweeps, beam imminent signals and beam crashes. Four access states re provided, No Access, Controlled Access, Restricted Access and Safe.

In the No Access mode the area has been cleared of personnel, all gates are reset and locked, all keys are in the key trees in the main control room [MCR key tree] and the radiation sources are enabled.

Controlled Access mode is used for short entries with a limited number of entrants and makes it possible to enter and exit an area and not require that the area be re-swept before going to the No Access mode. In this mode the radiation sources are disabled and entry requires the entrant to carry a key from the MCR key tree, to log in and out and be observed at the gate by a gate watch. At the gate the entrants presents themselves to local gate watch or over a closed circuit television system the remote watch in MCR and opens the gate with the key and a gate release from MCR. For exit a MCR gate release is also required.

Restricted Access is used for extended access periods and requires that the area be re-swept before going to the No Access mode. In this mode the radiation sources are disabled. Any person with an entry card that is valid for the area may enter.

Safe mode is the default mode when a problem is detected [e.g. wiring problems, ODH issues, etc.] The entry procedure is similar to Controlled Access. ODH requires that PASS monitor the air for the oxygen content and activate alarms and emergency ventilation if a significant deviation from normal is detected.

3. System Design

PASS uses networked Programmable Logic Controllers [PLC] as the basis of the system. In order to provide the required dual independent protection the area served by PASS is subdivided into 3 sub-sections each of which is served by two independent PLC's [field machines]. These field machines are separately networked [field network] into 2 divisions [A and B]. Each division independently provides full protection. For operational convenience there are two sets of A and B divisions [sub-systems] forming the SEB areas [A and B lines and the switchyard],

figure 1. Each field machine provides full protection for its associated sub-section. Operator interface is through touch screen displays [LCD Touch Panels] on a command network that is connected through firewall machines to the separate divisions.

3.1 Field Machines

Individual field machines supply all functions needed to insure the safety of personnel in associated area. Communications to the command network consists of status information and state commands from the user interface that are accepted by the field machine if and only if they are consistent with the status of the associated area. Each field machine independently controls and monitors the critical devices, gates, ODH (if applicable) beam abort (crash system), and monitors the sweep. Control of individual devices by the two divisions is implemented with relays in order to isolate the divisions. Divisions A and B utilize different series of Allen-Bradley PLC's [SLC 5/04's or 05's in division A and PLC 5's in division B] in order to reduce the probability of a common mode failure. In addition the two divisions are programmed by different programmers, working independently from a common engineering specification [state tables].

3.2 Critical Device Control

Critical devices are arranged in pairs and each one is disabled independently by the A and B divisions. Allen-Bradley PLC Remote Input/Output [RI/O's] blocks are the interfaces between the individual field machines and the critical device system. Use of this standard communication interface provides a supervised link with defined failure response. Critical device status is monitored through the same RI/O's. If, after an appropriate response time, a critical device does not respond as safe when disabled an additional device [or pair] is disabled [Reachback]. For the beam transport to the switchyard a beam plug is used as critical device and the SEB lines transport magnets are used as critical devices except at low energies [injection into the booster] where beam stops are used. The interlocking of the Booster inject beamstops is done thought the existing relay based interlock system. When an area is placed in the No Access mode visual and auditory beam imminent warnings are activated for a period before the critical devices for the area are enabled.

3.3 Gate System

There are a number of different types of gates, entrance gates, internal gates, and separation gates. All gates are equipped with two switches, which indicate that the gate is closed, one for each division. Entrance gates and internal gates have electric strikes, with latch-indicating switches, emergency entry break glasses, with indicating switches, key switches for gate reset, sweep and gate release, system response lights and status indicators and a card reader for Restricted Access entry. Separation gates have key switches for sweep and system response lights and status indicators and are monitored by both corresponding peers. All gate switches are readout by discrete R\IO modules with 24vdc digital logic.

3.4 Beam Crash and Sweep System

In order to insure that no personnel are in the area when the radiation source is enabled it is searched by a sweep team that follows a proscribed path activating key switches at sweep check

stations that are readout in the same manor as the gate switches. When the area is put in the No Access mode warnings are activated prior to enabling the critical devices. If anyone is in the area at this time they activate the beam crash, which uses pull cord and actuator installed along the non-machine side of the aisles. These are also readout in the way as the gate switches.

3.5 ODH Systems

The oxygen sensors for the ODH system are located at high points in the covered areas, because we are concerned primarily with helium. Each location has a pair of sensors [one for each division] that are associated with a local display and alarm panel. At the local panel the measured oxygen is displayed and only the alarm state is readout by the local peer in the same way as the gate switches are. In the ring there is a set of exhaust fans and air supply vents, corresponding to each sensor, that are operated when a sensor alarms. If the area is in the No Access mode then the ODH alarms do not activate the fans and vents. There are manual controls located at entry gates that activate all fans and vents.

3.6 PASS Command System

In each division the field network is connected to a master PLC [Fig. 1], which translates commands from the operator interface into commands for the field machine. This machine collects status information from the field machine and transmits it to upper level machines. The firewall machine is the link between the command network and the master machines in each of the divisions. It is configured to permit data transfer to and from the individual divisions and the command network, but to prohibit communication between the two divisions.

On the command level networks are located behind the firewall machines for the two sub-system, the corresponding control Panelviewers [Fig. 2], alarm Panelviewer, access control console Panelviewer [Fig. 3] and a status logging PC. The control Panelviewers provide full access to all control functions and an extensive range of status information for the corresponding sub-system and are configured to permit communication with its sub-system only. Both subsystems report alarm information to the alarm Panelviewer. The access control console Panelviewer is intended for supervision of remote Controlled Accesses and is limited to providing gate releases and to selection of the gates to be viewed on the TV monitors. There is a pc that is running a very restrictive Allen-Bradley support program that permits it to log all activities on both sub-systems.

There are six key trees located in the PASS control racks [fig. 2]. Each tree captures the sweep/reset keys for an operationally integral part of the system and is required to be complete in order to place that area in the No Access mode. In some cases a series of trees is required to be complete.

4.0 Review and Testing

The basic defining specification for the system was reviewed and approved by the relevant safety committees and management. Based upon these specifications detailed documentation [state tables] was developed by an ad hoc committee that included PASS personnel and representatives of the safety committees. During the construction and programming of the system a series of

certification test procedures were developed for initial certification and periodic re-certification of the system prior to use. Upon completion of the initial tests and review and approval of the results the configuration of the hardware and software is fixed and becomes subject to formal configuration management. Subsequent modifications are reviewed and retested using a graded approach. In order to assure a consistent approach to the review and approval process, one member of the departmental safety division is the principle non-system reviewer.
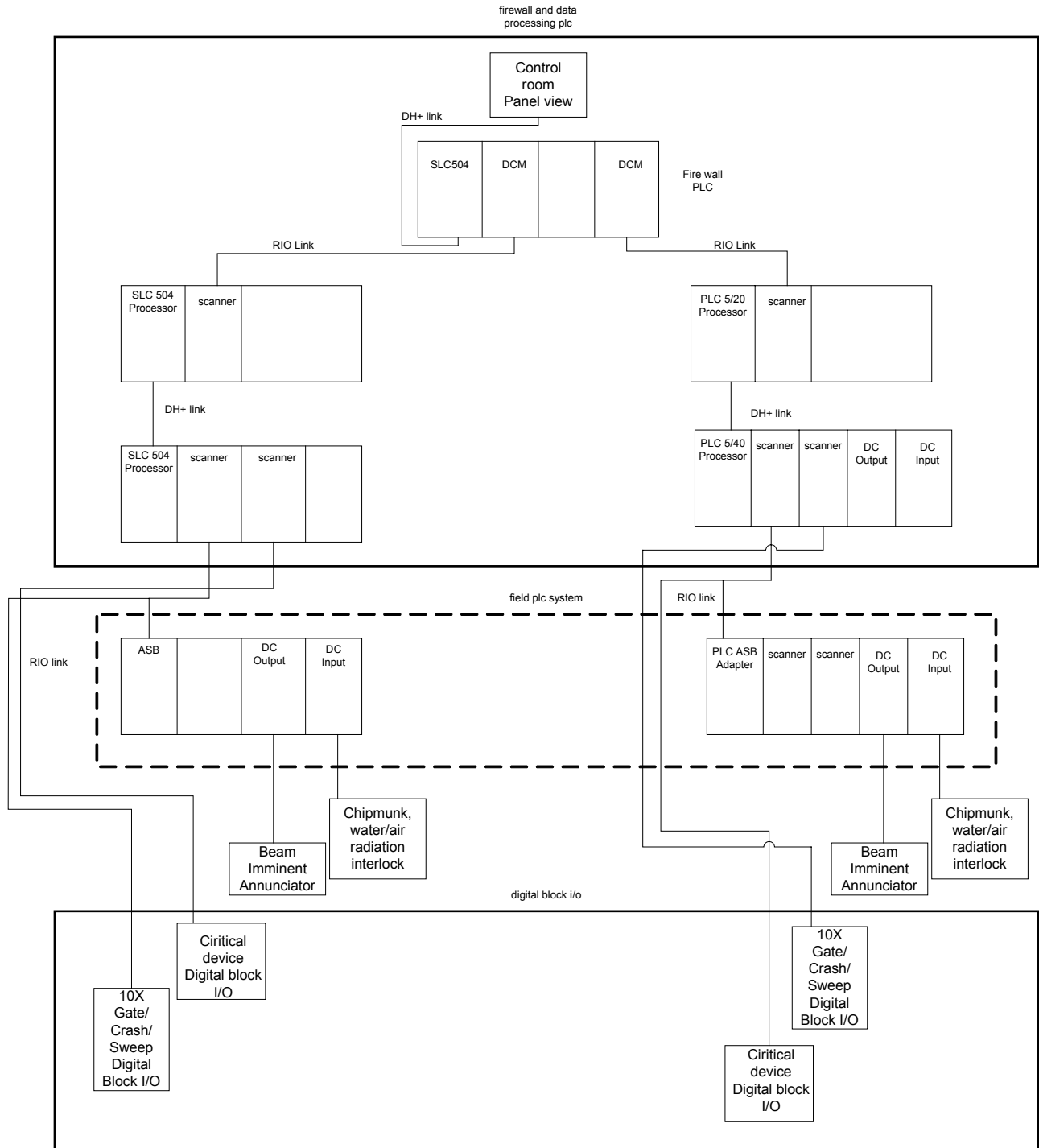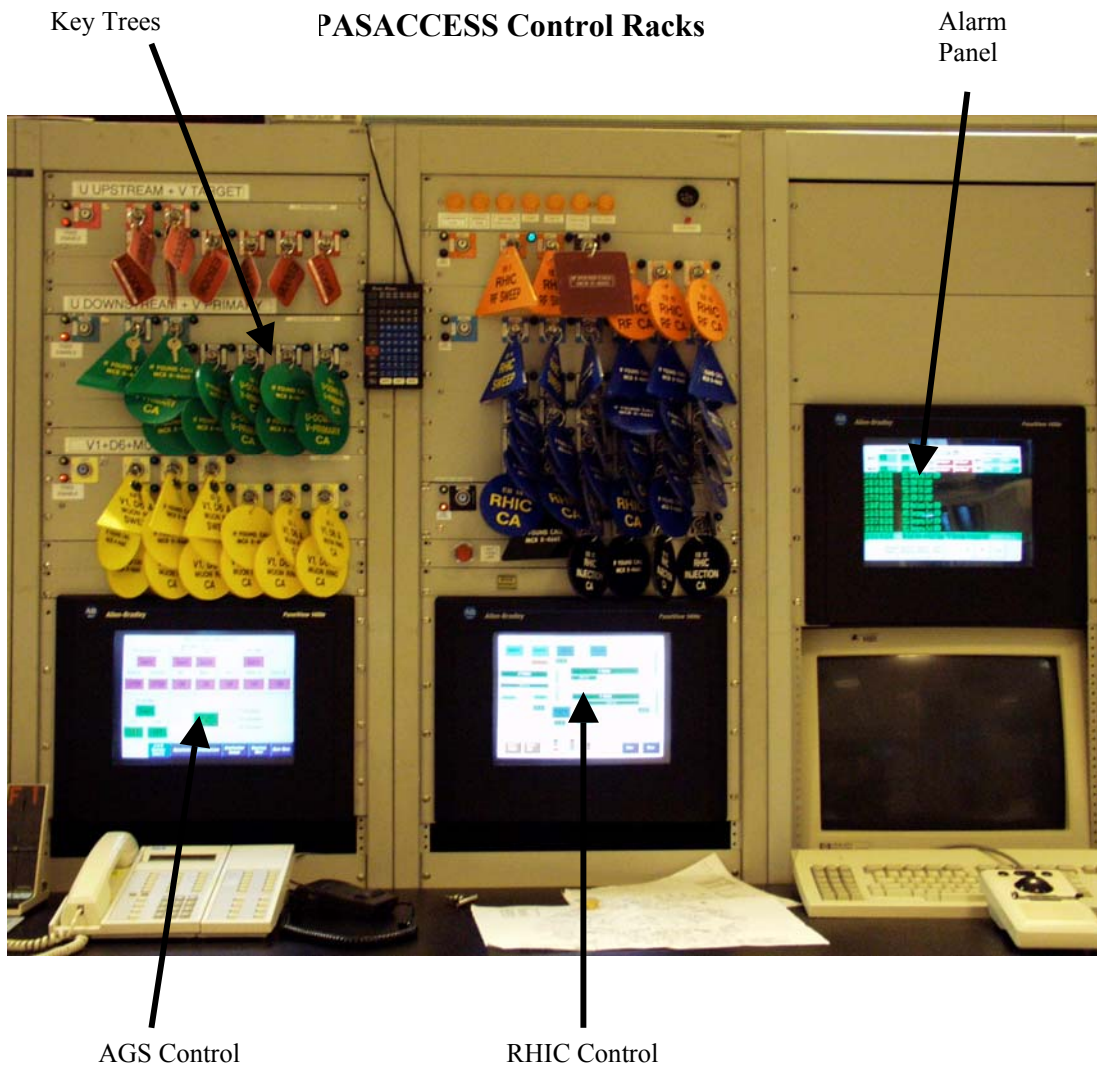
SEB PASS BLOCK DIAGRAM

Figure 1

PASACCESS Control Racks

Key Trees

Alarm Panel

AGS Control

RHIC Control

Figure 2

PASS MCR Access Control Console

CCTV
Monitors

Panel viewer Controls

Figure 3

Chapter VI. Controls

1. Scope of Work

The C-AD Controls Division will provide computer controls for various subsystems to be constructed or modified for the RSVP project. These controls will be compatible with existing standards in use at the AGS and RHIC. Existing designs and/or commercial hardware will be utilized, and only a small amount of software development will be required. Configuration of database and software for the new interface modules will be required.

 The following table lists the subsystem elements addressed in the various Controls tasks:

Project Task	Controls Task	Subsystem Elements
Booster/AGS	Booster Instrumentation Interface Hardware	Loss monitor and beam inhibit interfaces; collimator motion control; harp gain control
	Booster Instrumentation Software and Database	Front-end software configuration for above elements; console application software for loss monitor
	AGS Instrumentation Interface Hardware	Motion control for extraction magnet systems; ring ground system interface
	AGS Instrumentation Software and Database	Front-end software for magnet motion control; database configuration for motion systems, loss monitors, current transformers, flag systems and ring grounds
	AGS Power Supply Interface Hardware	Interfaces for new extraction magnet power supplies
	AGS Power Supply Software and Database	Database configuration for power supplies
Switchyard	Instrumentation Interface Hardware	Hardware interfaces for EPMs and/or SWICs, loss monitors, collimators, scanning targets and current transformer
	Instrumentation Software and Database	Database and front-end software configuration for above elements
	Power Supply Interface Hardware	Control cabling for magnet power supply relocation
	Power Supply Software and Database	Database configuration for above elements

Project Task	Controls Task	Subsystem Elements
KOPIO	Instrumentation Interface Hardware	Hardware interfaces for EPMs and/or SWICs, loss monitors and beam inhibit, flag, target telescope and target temperature monitor
	Instrumentation Software and Database	Database and front-end software configuration for above elements
	Power Supply Interface Hardware	Control cabling for magnet power supply relocation
	Power Supply Software and Database	Database configuration for above elements
MECO	Instrumentation Interface Hardware	Hardware interfaces for EPMs and/or SWICs, loss monitors and beam inhibit, current transformer, collimators, flags, target telescope and target temperature monitor
	Instrumentation Software and Database	Database and front-end software configuration for above elements
	Power Supply Interface Hardware	Control cabling for beam-line magnet power supply relocation; new interfaces for MECO superconducting magnets
	Power Supply Software and Database	Database configuration for above elements; front-end software and console application configuration for MECO magnets

2. Method

The control system hardware assembled for this project will be identical in all respects to equipment in use at the C-AD facilities. Standard VME chassis will be configured with appropriate interface modules for the RSVP subsystems. These chassis will be connected to the existing fiber-optic infrastructure providing Ethernet and timing connections with the central servers and control room. Network switches, remote power reset modules, and terminal servers will be required for new equipment locations.

In the Booster and AGS, the new interface modules will be installed in both four (4) new and three (3) existing chassis. Most of the switchyard interfaces will be installed in two (2) new chassis installed in the instrumentation electronics racks. A few downstream switchyard instrumentation interfaces will be located in the MECO/KOPIO beam-line chassis because of cable length constraints. The KOPIO and MECO beam-line instrumentation electronics will be located together. The interfaces will require one (1) dedicated chassis for each experiment and two (2) shared chassis, one of which will be dedicated to the loss monitor and beam inhibit

system. The MECO superconducting solenoid power supplies will also require a dedicated VME chassis and a PLC unit for state control and monitoring. Each chassis will contain a microprocessor module, a general utility module for timing input and a battery powered cache memory module to preserve configuration across reboots. Timing delay modules, signal fan-outs, scalers, and analog and digital I/O modules will be configured according to the needs for each subsystem.

Each instance of new equipment interfacing will require database configuration for access by front-end application interface software for control and monitoring, including alarms. Very little new application software will be required. A notable exception is the Booster loss monitor application for the main control room. A new application will be needed that is designed for the new interface hardware using modern graphical user interface tools.

Chapter VII Instrumentation

RSVP Instrumentation
Transport from AGS to MECO & KOPIO Targets

Common to MECO & KOPIO
C-10 SEC
C-11 SWIC
C-36 Scanning Target
C-50 Current Transformer
AQ5 (US) EPM
AD2 (US) EPM

A-Line (MECO)	B-Line (to KOPIO)
AQ6 (US) EPM	CQ8 (US) EPM
AD3 (DS) EPM	BQ9 (US) EPM
Current Transformer 1	BD8 (DS) EPM
AQ10 (DS) EPM	BQ10 (US) EPM
AD4 (US) EPM	BQ11 (US) EPM
AD5 (US) EPM	BQ12 (US) EPM
AQ15 (US) EPM	
Current Transformer 2	

A-Target MECO:	**B-Target KOPIO:**
Flag & Video	Flag & Video
Loss Monitors	Loss Monitors
Telescope	Telescope
Target Temperature Monitor	Target Temperature Monitor
Pin Diodes	

Notes: 1. Loss Monitors (short & long) will be distributed throughout the beam transport.
2. Loss Monitors in picture frame configuration in front of each target station.

Definitions:
SWIC: Segmented Wire Ionization Chamber
EPM: External Profile Monitor
SEC: Secondary Emission Chamber
Telescope: Three Scintillator/PMT assemblies aligned to detect coincident secondary particles from the target.
US: Upstream
DS: Downstream

1. External Profile Monitor

1.1 Introduction:

The residual ionization beam profile monitor has been used in C-AD accelerators for a long time. It makes use of multiple traversal of the beam through the high vacuum residual gas to produce enough ionization for observation. The device is normally called IPM (Internal beam Profile Monitor). It was realized that the AGS external beam area is another candidate application of this principle. In the switchyard, the vacuum was in the micron range, before the 1995 AGS high intensity upgrade. The beam intensity was less than 10 TP in the individual beam lines. The combination of intensity and vacuum uniquely provided the opportunity for a new device, EPM (External beam Profile Monitor). After the AGS high intensity upgrade, the vacuum in the switchyard deteriorated to tens of micron's. This spoiled the capability of the EPM. The device

can no longer function as a beam profile device as the excessive number of ions produced caused undesired broadening of the measurement. RSVP requires a very high intensity beam, 100 TP per pulse and spill rate about 20TP per second. It becomes desirable to revive this device for RSVP application, since it is not intrusive and requires no material in the beam. The study is aiming at the possibility of extending the range of external beam transport vacuum for EPM operation.

1.2 EPM Operation Principle

The charged particle path through a material or gas causes the atom/molecule to be ionized. Collecting this ionization gives us the intensity distribution of the charged beam. We have applied this principle in Segmented Wire gas Ionization Chamber (SWIC), used extensively in the heavy ion beam lines, and some secondary charged beam lines. In normal air, the ionization of a minimum ionizing particle creates about 60 ion pairs in one centimeter. In vacuum, at around one micron pressure, the secondary ionization no longer exists/dominates. The primary ionization is about 12/cm of STP air. When 10^{12} protons (1TP) travel through 10cms of air, the following charge is produced;

$$10^{12} \text{ x } 12 \text{ x } 10 \text{ x } 1.6^{-19} = 19.2 \text{ micro Coulomb}$$
For 1 micron, 10^{-6} of STP. We then get 19.2 pico Coulomb.

This is at the low end of our normal integrator electronics dynamic range at the time of the original conception. On the other hand, the intensity could be higher and the vacuum is not exactly at 1 micron.

1.3 EPM Design

The primary design concern is to create a simple and flexible construction. We utilize an end plate mounted system using a 12" beam pipe as housing. Figure 1 shows the design detail.

The collecting and bias plates are mounted on rods which are mounted on the supporting end plate. There are two sets of plates, one for horizontal and the other for the vertical measurement. The "signal plane" is a printed circuit board with strips 2 mm apart, shown in figure 2.
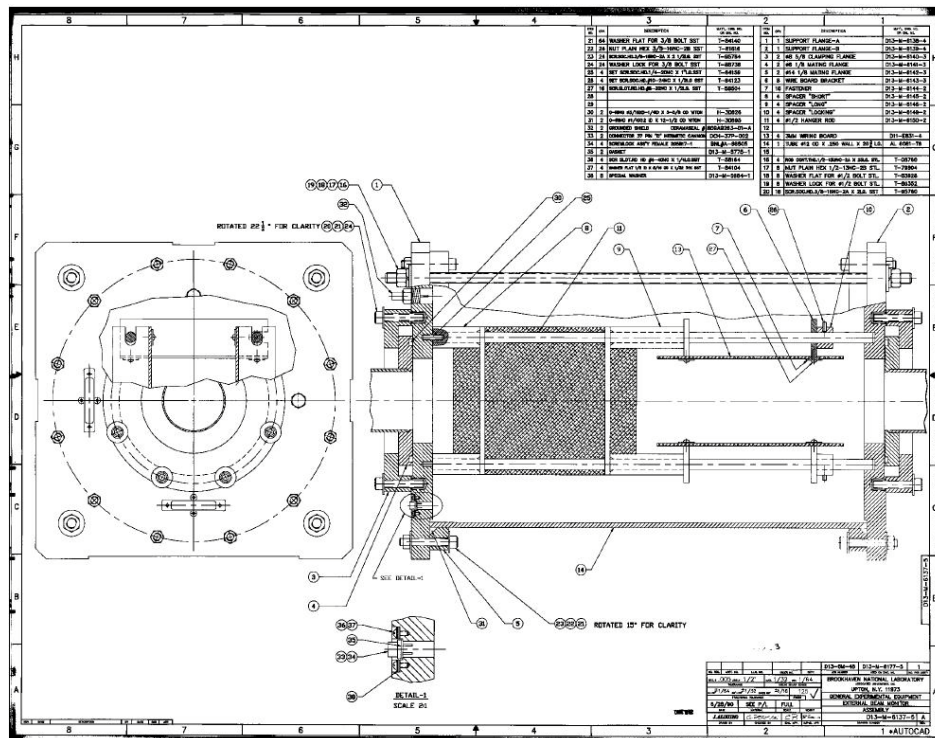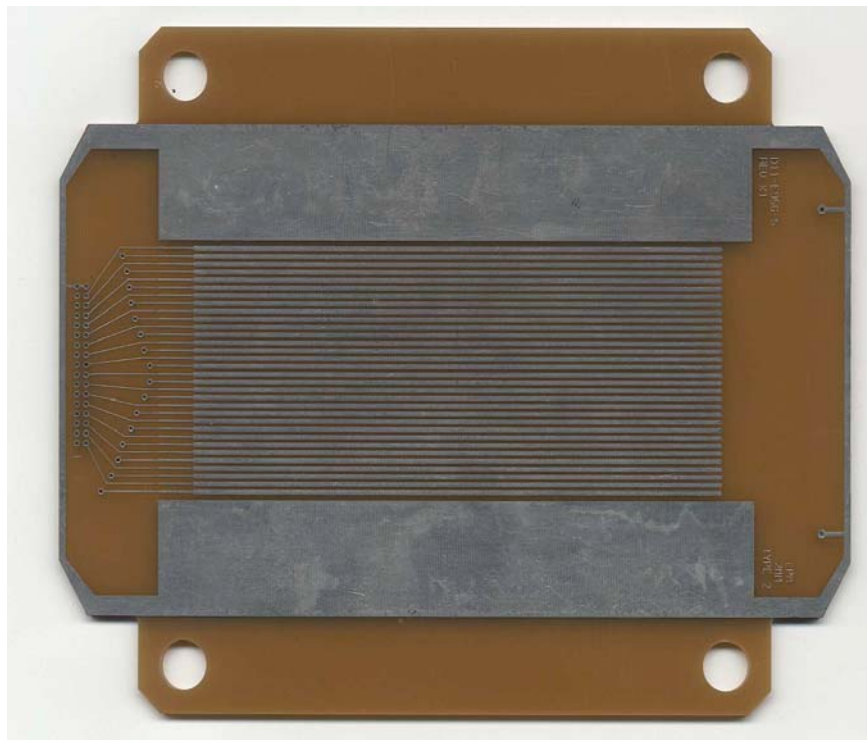
Figure 1. EPM Drawing

Figure 2. Signal board.

On top of the signal plane, there is a guard plate to shape the electrical field, Figure 3. The active area of the collecting region is 14.7 cm along the beam direction. The maximum beam active width is 2 mm x 32=6.4 cm. The distance between signal and bias plane is 10 cm. This limited the beam size to be less than 10 cm to avoid obstructing the beam. Figure 4 shows the detectors mounted on the rods, and Figure 5 shows the actual device mounted in the D line transport.
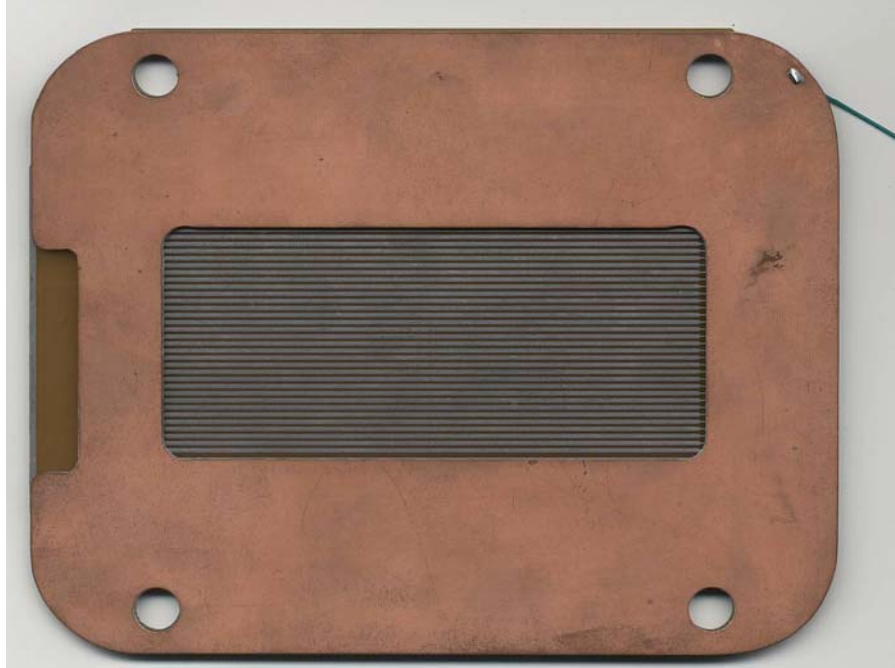

Figure 3. Signal board guard plane.

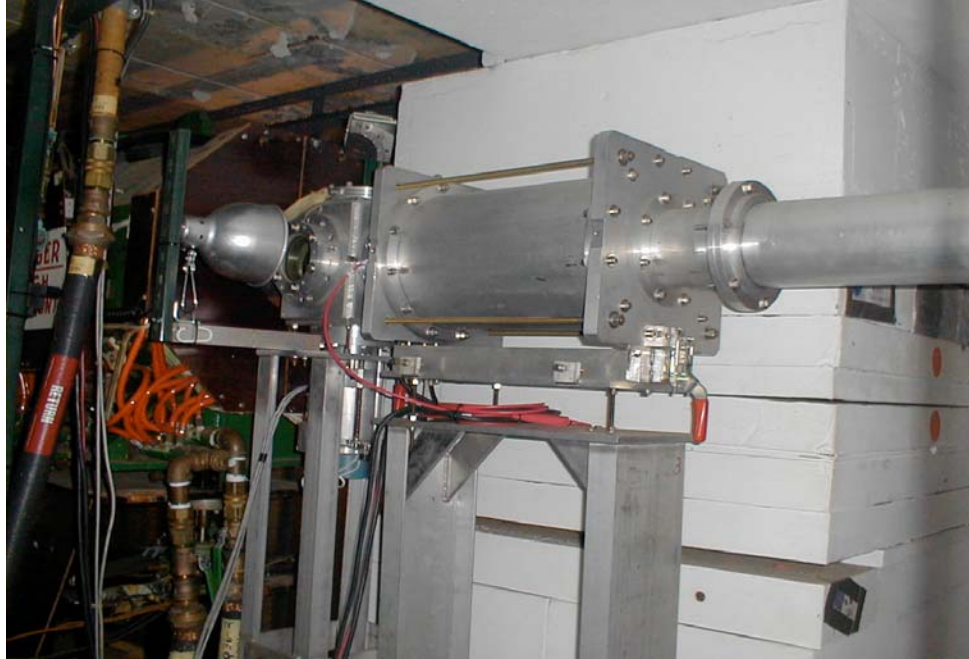**Figure 4.** Photo of the detectors mounted on the end plate.

Figure 5. Finished EPM mounted in the D line transport.

1.4 Vacuum limitations

As the ions drift in the vacuum they will collide with the residual gas. The average length of travel is about 5 cm. The "estimated" collision length is about 1.0×10^{-5} cm at STP. At 1-micron vacuum, the collision length becomes 10 cm. This puts the normal operating vacuum of the EPM in the 1-micron range. Fig. 6 shows the maximum positive voltages we could apply on the bias plane vs. the vacuum. The pump used in the test setup limits the lowest vacuum. For good operation, the vacuum needed to be 10 microns or less (for more than 2 kV applied across the 10 cm gap).
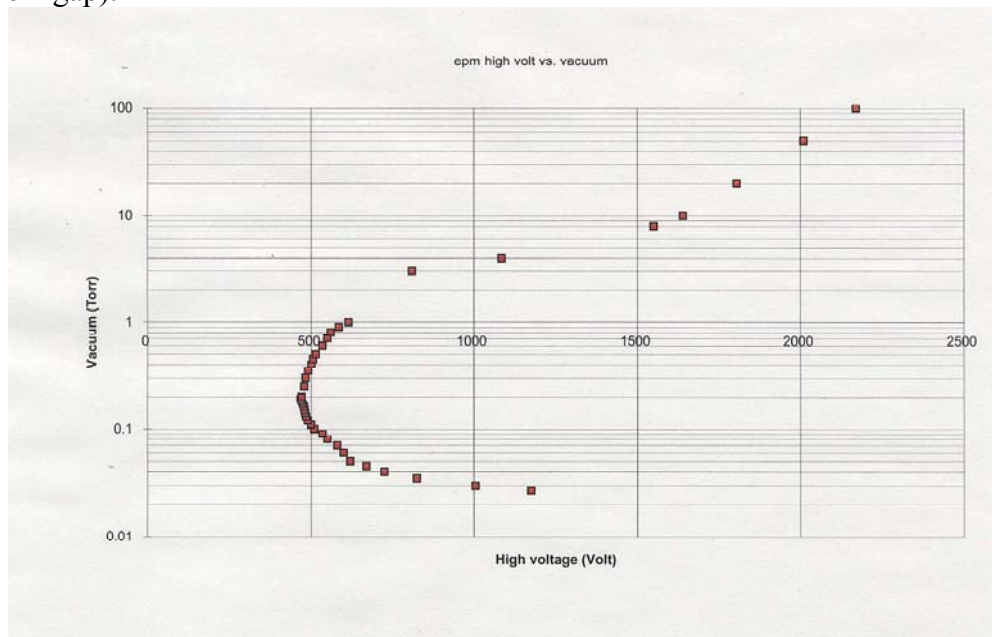

Figure 6. Maximum voltage of EPM vs. Vacuum in the EPM.

1.5 Performance:

With D line Vacuum on the order of one micron and the beam intensity of 7 TP. The three EPM's, D224, D355 and D380 profiles are shown in Fig. 7. The integrator is at high gain (1.0 nano farad) and the display gain set at 2. The display is at .5 volts per cm. The profile remains fairly constant when bias voltage is more than 2 kV. We normally operated at 4 kV positive bias voltage. The estimated collected charge is about 1,600 pico coulomb. (The integrated area is 18 Volts. The gain is factor of 2 and the capacitor is 182 pico farad) This gives about 230 pico coulomb per TP. It is more than a factor of 10 better than the estimated ionization of 1-micron pressure. Part of the answer could be that the pressure is really more than 1 micron and other could be that the residual gas is more ionized. It is welcome news for the EPM application.
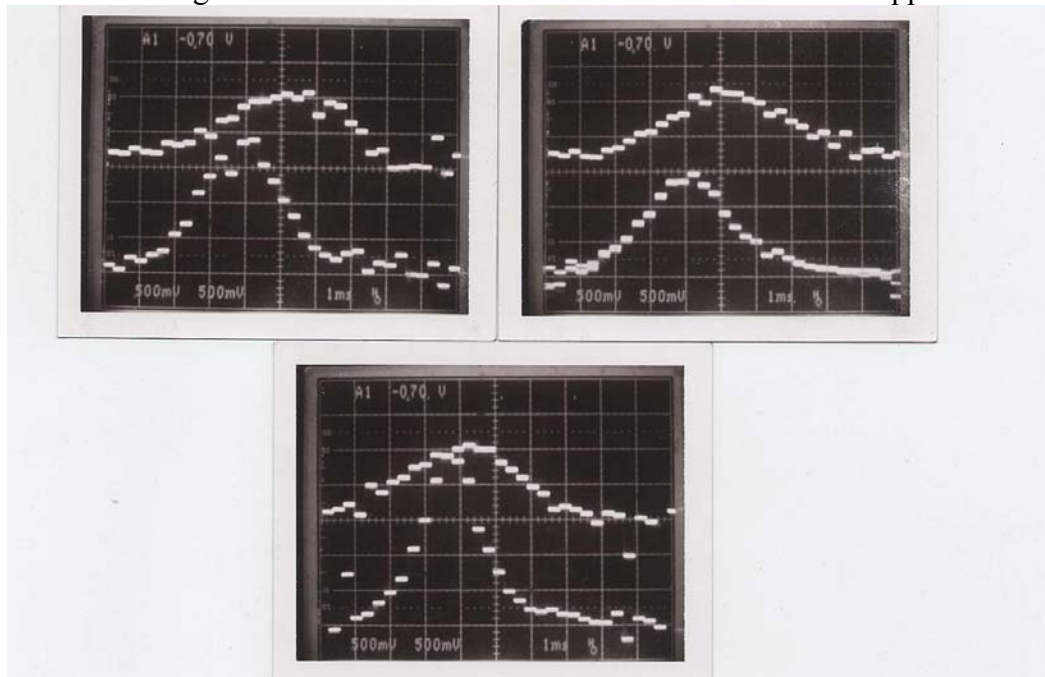

Fig. 7. Scope trace for the Horizontal and Vertical profile of 3   EPM.

2. KOPIO high Intensity Requirements:

The new RSVP experiment will demand 100 TP beam extracted and delivered to the target station. Two problems arise with the current instrumentation;

1   The beam intensity monitor is needed. The old SEC (Secondary Emission Chamber) is known to deteriorate; the secondary emission coefficient is reduced by almost 40 % after one year of 40 TP running.
2   Need for less intrusive detector for beam profile monitor: The SWIC and Flag will create unnecessary beam loss in the beam transport system. This will reduce the effectiveness of these devices.

In this context, the EPM idea was revitalized. We could use EPM to monitor the beam both in profile and intensity. For the intensity, we need to monitor the vacuum pressure and also the

components of the residual gas. The first step of the development is to check on the vacuum requirement of EPM. We know it works with l micron vacuum, but how far could we relax the vacuum requirement?

2.1 Modification of EPM:

We know from experience that the EPM profile and amplitude grow to unmanageable levels when the vacuum spoils to more than 30 micron. That is why we stopped using the device when the vacuum in the Switchyard was spoiled. The idea of confining the electrons with magnetic field was used in the accelerator IPM. Adding the magnetic field in the drift direction should confine the spread of signal. It is not clear how collisions will disperse the signal width since electrons should have 4 times longer collision length (assuming the size of electron is zero compare with atom), the collision effect should be smaller. On the other hand, the electrons will have a higher intrinsic velocity, thermo motion and recoil momentum in the ionization process. The magnetic field will minimize these effects on the profile.

2.2 Magnetic Field:

The simplest way to add a magnetic field is using permanent magnets. Figures 8 shows the modification.

Figure 9. The detail indicating the addition of the permanent magnets.

3. Profile Monitors: Segmented Wire Ionization Chamber

The Segmented Wire Ionization Chamber (SWIC) located 11 feet from the exit of the AGS ring will measure transverse beam horizontal and vertical profiles. This type of device has been used extensively at C-AD during previous high intensity proton experiments. Due to the semi-destructive nature of this measurement, we will incorporate remote control plunging capability.

Typically this is an array of 32 thin signal wires in each of the horizontal and vertical planes sandwiched between high voltage planes, and argon-CO_2 gas flows through the entire head assembly. The plunging head assembly is separated from the vacuum by thin aluminum windows. A similar device, although on a slightly larger scale, is successfully employed at the NSRL facility, see picture below.

Figure 10. Plunging SWIC assembly in the NSRL beamline.

SWIC signal processing electronics will be a C-AD standard Eurocard based integrator configuration, we will modify an existing electronics package, which will include remote control gain and appropriate integrator capacitor values for RSVP type beams.

4. Profile Monitors Scanning Target

The scanning target will be located in the upstream portion of the external beam transport in the AGS ring enclosure. It provides the ability to measure transverse beam profiles, with enhanced capability in probing the characteristics of the beam halo. These measurements are used to arrive at emittance characteristics, which are important tuning parameters while setting up extraction. Understanding & minimizing beam halo is critical to minimize beam losses and optimize transport efficiency. This measurement is done by scanning two separate electrically isolated

thin horizontal and vertical tungsten targets across the beam path while measuring the secondary emission current from the targets, and the scattered secondary particles using scintillators and photomultipliers in a telescope configuration as shown in figure 11.
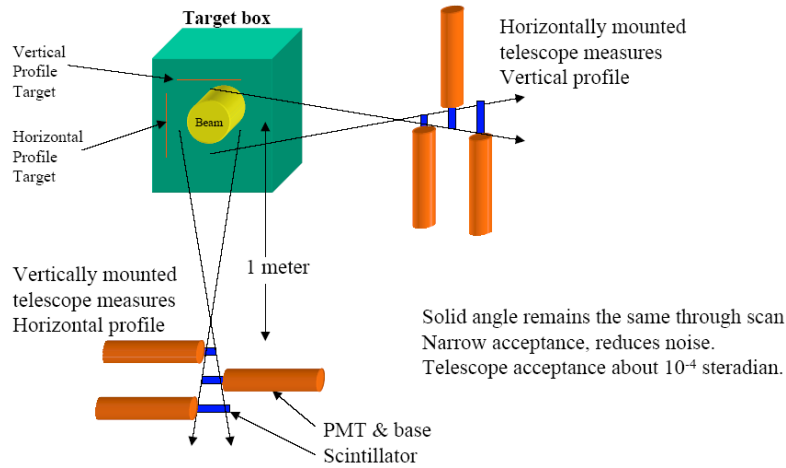

Figure 11. Schematics of a scanning target device and detector.

Past experience with this device resulted in beam profile measurement with 2 to 3 orders dynamic range with the secondary emission signals, and 4 to 5 orders with the telescopes, and good agreement between the two techniques. For the RSVP application we plan on improving performance by revising the target design, replacing any rad-damaged components, and upgrading the motion controls to the standard for similar systems.
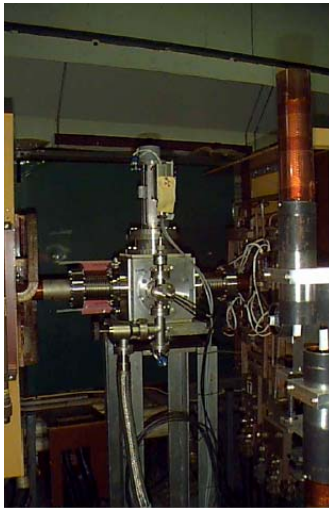

Figure 12. Installed target scanning device.

5. Current Transformer

The most basic measurement on a beam is that of its intensity. A widely used device is the "Current Transformer" which allows one to determine the electric current that a beam constitutes

or, depending on the circumstances, the electric charge contained in a burst of beam. Figure 13 shows the principle and beam line assembly.
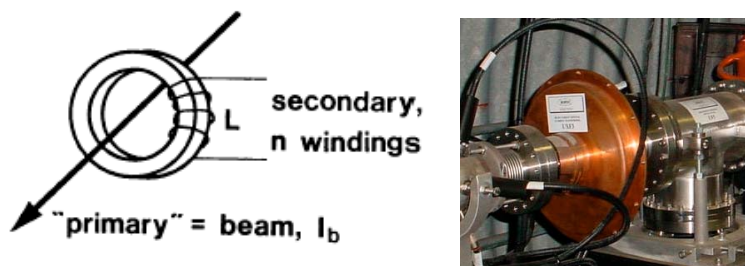

Figure 13. Current Transformer principle, and assembly in copper shroud

A current transformer will be installed in the upstream portion of the external beam transport in the AGS ring enclosure. We will use an existing transformer detector assembly which was employed previously for measuring single fast extracted bunched beam intensities. For RSVP we will purchase commercial electronics from the same manufacturer which is capable of measuring the RSVP beam.

In the MECO transport beamline, there will be two matched current transformers assemblies, one upstream and one downstream of the Lambertson's. Using a BNL modified version of the available commercial signal processing electronics, an extinction measurement can be made. This extinction measurement feature was eliminated during cost cutting, so we will only provide one set of electronics, but will order two toroids since they can be accurately matched during production. Using the one set of standard electronics for the downstream MECO transformer will enable overall external transport efficiency measurements with a few percent accuracy. The beamline assemblies include a necessary ceramic break, copper shroud, and calibration winding, and will be similar to existing C-AD devices. The toroids and standard electronics are commercially available from Bergoz. The signal processing electronics will provide average current measurements and a calibration technique.

6. Secondary Emission Chamber

A secondary emission chamber (SEC) provides a semi-destructive measurement of the beam intensity versus time. For the RSVP application, a standard SEC design will be modified to include plunging capability which will allow measurements during tuning and troubleshooting, and the capability to remove it during running periods. The assembly structure can be described as an evacuated chamber with 5 thin aluminum foil planes that are situated perpendicular to the beam trajectory. Three of the planes are high voltage bias (+450 V), two of the planes (A & B) are for Signal pickup (virtual ground). The configuration of these five planes is HV-S-HV-S-HV; the Signal (S) planes are sandwiched between adjacent High Voltage (HV) planes. See figure 14 for a view of chamber assembly and internal structure.
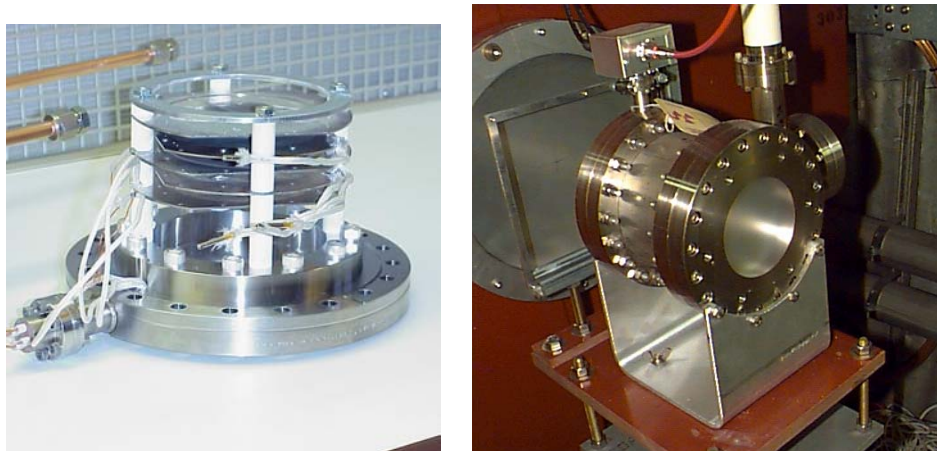
Figure 14. Secondary Emission Chamber internal and full assembly.

As the beam passes through the foils, electrons are released from each of the foil surfaces at a rate of about 2.2% per proton. Since there are two signal planes, each with two sides, this yields four sides (with relative negative voltage potential) producing (emitting) electrons. The two (A & B) signal planes are typically joined electrically (externally) to sum the currents. So a net 8.8% production is realized.

Signal conditioning is done via a long coax cable to an op-amp based integrator circuit that provides analog (current to voltage conversion) and digital (current to frequency conversion) measurement data. A rate interlock circuit is also included which has adjustable rate thresholds and can generate a beam inhibit trigger to turn off extraction in the event of an inadvertent undesirably high spill rate.

7. Loss Monitors

In order to provide machine protection throughout the machines and the transport beam lines, and allow "hands-on" maintenance, as well as a tool for tuning, the beam loss monitor system will be critical for minimizing losses and optimizing efficiency. Ionization chamber detectors are installed adjacent to the beam vacuum chambers. These argon-CO_2 filled chambers provide a calibrated current signal which originates when minimum ionizing secondary particles (generated when primary beam hits vacuum chamber apertures) cause pair production in the argon-CO_2, this charge is collected on a signal electrode by applying a bias voltage across the chamber. The loss signal is routed to integrator based processing electronics which provides data to the beam inhibit, loss accounting, and high level data display application systems. In the Booster, AGS, and transport beamlines, the ion chamber detectors are typically sealed 3/8" or 7/8" Heliax cable, which are either pressurized, or flow the argon-CO_2 gas.

8.0 Target Instrumentation

8.1 PIN Diodes

PIN Diodes will be employed as a high sensitivity directional loss monitor near the MECO target magnet. These devices have proved useful at many accelerators. Since they are solid state electronic based, they will not suffer from stray magnetic field interference, but are susceptible to high levels of radiation. We will be able to learn a lot about targeting parameters during the early transport setup effort.
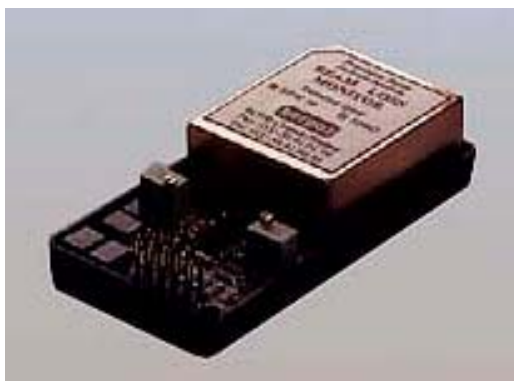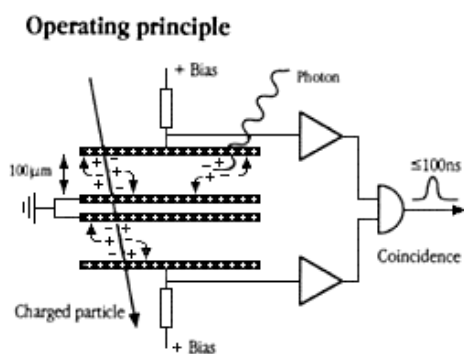

Figure 15. PIN Diode operation principle diagram, and detector assembly, both courtesy of Bergoz.

These devices are commercially available from Bergoz. We will build custom enclosures for each, as well as a power and calibration control chassis.

8.2 Telescopes

Another diagnostic commonly used for similar fixed target experiments is the telescope. It is essentially a linear array of three scintillator photomultiplier-tube (PMT) assemblies positioned carefully so that secondary particles only from the target will pass through all three scintillators. The signal processing electronics condition the analog PMT signals, then feed a coincidence stage which generates pulses that are monitored by the Controls system. This system has been proven to provide valuable data regarding targeting efficiency.
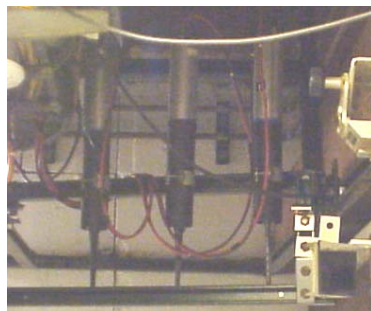

Figure 16. Telescope assembly for fixed targets.

8.3 Target Temperature Monitor

The temperature of the fixed targets will be monitored via thermocouples; this data will be used as an input to the beam inhibit system to ensure against target damage, and as a reference for targeting efficiency. The thermocouples will be placed on the outer heat jacket in a variety of locations to measure heat distribution and for redundancy. An Allen Bradley PLC system will be employed to process the signals, provide data, and compare measured temperatures to predetermined operating thresholds.

8.4 Target Flag

In order to optimize the beam targeting parameters, a thin Al-Ox phosphor flag will be mounted in the beam path and viewed by a nearby radiation hardened video camera. A rad-hard multi-position neutral density filter will be used to extend the system dynamic range. The image will digitized via frame grabber for detailed analysis, and available for display live throughout the complex. This flag-video diagnostic has been used successfully for many high intensity proton fixed target experiments.

Figure 17. Conceptual KOPIO target & flag configuration, and similar rad-hard camera assembly installed in the Booster ring.

8.5 Target Loss Monitors

Several ion chamber loss monitors will be installed near the targets. An effective configuration used to monitor and diagnose beam transport parameters is what we call a "picture frame", this entails loss monitor detectors mounted above, below, to the left, and the right of the beam vacuum chamber just upstream of the last large quadrupole before the target. The mounting bracket, which holds the detectors, looks like an empty picture frame centered around the beam transport vacuum chamber. The quadrupole acts a shield to block backscatter secondary particles from the primary target.